STATE OF MONTANA
NATURAL RESOURCE DAMAGE PROGRAM

REBUTTALS TO ARCO'S GROUNDWATER INJURY REPORTS

OCTOBER 1995

Missoula

Clark Fork River

Butte
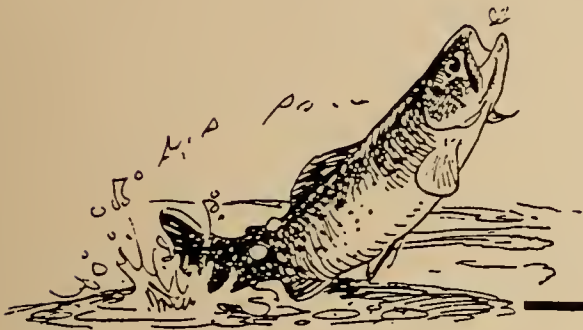
REBUTTALS TO ARCO'S GROUNDWATER INJURY REPORT BY REMY HENNET AND STEVEN P. LARSON

PREPARED FOR
STATE OF MONTANA
NATURAL RESOURCE DAMAGE PROGRAM

OCTOBER 1995

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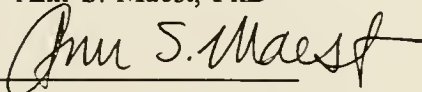STEVEN P. LARSON

Final Report

Prepared for:

STATE OF MONTANA
NATURAL RESOURCE DAMAGE
LITIGATION PROGRAM

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October 18, 1995

CERTIFICATION OF

DR. RICHARD J. BRAND

I, Dr. Richard J. Brand, certify that I am prepared to offer opinions and testify as to the appropriateness of the statistical methodologies used, and statistical results and conclusions reached in sections 4.0, 5.0, 7.0, 8.0 and 10.0 of this rebuttal to ARCO's Groundwater Injury Reports and that I subscribe to all of the opinions, bases and reasons stated in those report sections involving such statistical methodologies, results and conclusions.

_____   10/16/95
Dr. Richard J. Brand   Date

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Acronyms

ARCO	Atlantic Richfield Company
AWWA	American Water Works Association
CBD	Commerce Business Daily
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
MBMG	Montana Bureau of Mines & Geology
MCL	maximum contaminant level
NRDA	natural resource damage assessment
SMCL	secondary maximum contaminant level
USGS	United States Geological Survey

Rebuttal to ARCO's Groundwater Injury Report by Hennet and Larson

1.0 Introduction

ARCO released groundwater injury reports in the form of expert reports by Remy J-C. Hennet (Hennet 1995) and Steven P. Larson (Larson 1995). The comments below address issues in the expert reports concerning groundwater geochemistry, which is largely addressed in the Hennet report. The topics covered include: defining injury using sulfate, iron, and manganese; location of Butte baseline bedrock wells in unmineralized or mineralized areas; location of baseline bedrock wells in the Central Ore Zone; use of Meinzer and Botz data to estimate baseline bedrock groundwater quality; ARCO's use of geochemical modeling to determine concentrations of contaminants in mineralized bedrock groundwater; baseline concentrations of nitrate in the Area I alluvial aquifer; sources of sulfate in the Anaconda area alluvial aquifer — possible influence of geothermal sulfate; possible attenuation of Anaconda groundwater plumes; and ARCO's use of cumulative frequency diagrams to show exceedence of relevant water quality standards.

2.0 Defining Injury Using Sulfate, Iron, and Manganese

ARCO takes issue with the State's use of iron, manganese, and sulfate to define and quantify injury (Hennet 1995, pg. 12). In order for groundwater to be injured according to NRDA regulations, samples taken from two wells more than 100 feet apart in the same hydrogeologic unit must be shown to exceed relevant standards in groundwater that was potable absent the release (43 CFR §11.62(c)(1) and §11.62(c)(2)). MCL and SMCL values defined under sections 1411-1416 of the Safe Drinking Water Act and drinking water standards for the State of Montana serve as relevant standards for defining injury in groundwater resources (43 CFR §11.62(c)(1)(i); Maest and Metesh, 1995).

For groundwater injured by nonhazardous substances, it must be demonstrated that the substances causing the injury occur in the groundwater resource as a result of physical, biological, or chemical reactions resulting from or initiated by the release of hazardous substances (43 CFR §11.62(c)(4)). Figure 1 is a generalized description of how injury is defined according to NRDA regulation. Figure 2 describes how nonhazardous substances, such as sulfate, iron, and manganese, occur in groundwater as a result of reactions involving hazardous substances. A more detailed description of Figures 1 and 2 is provided below:

Figure 1
Generalized Flow Chart Demonstrating that Nonhazardous Substances Causing Injury
Result from Reactions Involving Hazardous Substances

**Determine Groundwater
Exceeds Standards for
Non Hazardous Substances**

**Relevant Standards
Exceeded in
Two Wells
> 100' Apart**

**Demonstrate Non Hazardous
Substances Causing Injury
Result from
Reactions Involving
Hazardous Substances**

43CFR §11.62 (c)(4)
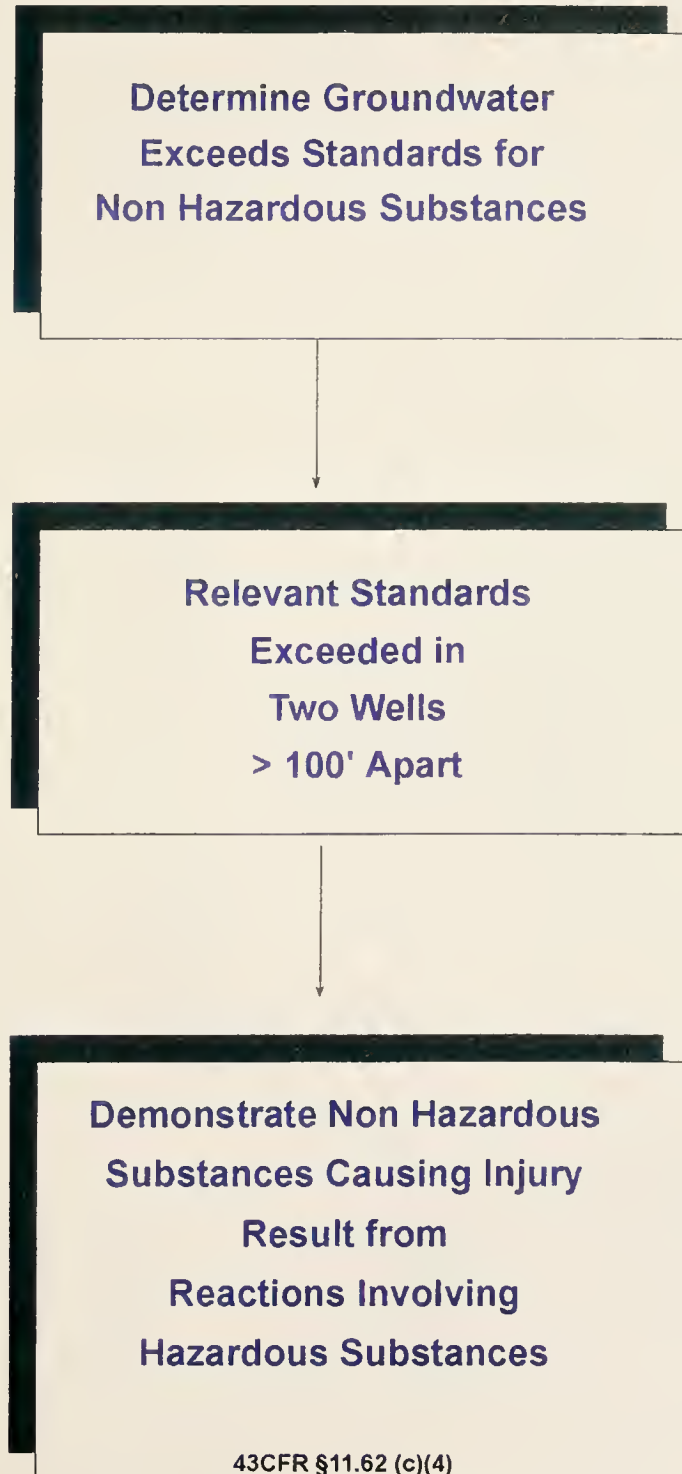
Figure 2

Demonstration that Nonhazardous Substances Causing Injury at the Clark Fork NRDA Sites Result from Reactions Involving Hazardous Substances

RELEASE OF HAZARDOUS SUBSTANCES:

(photo of mine waste)
1

Hazardous Metal/Metalloid Sulfides in Mine Waste (e.g., $CuFeS_2$, Cu_3AsS_4)

(photo of acid mine drainage)
2

Ferric Sulfate and Sulfuric Acid in Acid Mine Drainage

(photo of leaching operation)
3

Sulfuric Acid Added to Underground Workings and Used in Leaching

REACTIONS INVOLVING HAZARDOUS SUBSTANCES:

Hazardous Sulfides + Air + Water

Hazardous Sulfides + Microbes

Ferric Sulfate + Non Hazardous Minerals

Sulfuric Acid + Non Hazardous Minerals

SUBSTANCES CAUSING INJURY:

• Hazardous Metals/ Metalloids

(e.g., copper/ arsenic)

• Iron
• Sulfate

• Manganese
• Aluminum
• Fluoride

EXAMPLES OF PHOTOS TO BE USED IN
TOP THREE BOXES FOR FIGURE 2: DEMONSTRATION

1:    STREAMSIDE TAILINGS

CHALCOPYRITE
CuFeS$_2$
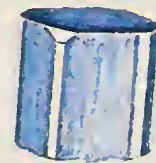
ENARGITE
Cu$_3$AsS$_4$

2: ACID WATERS ENTERING BERKELEY PIT

or

2: BERKELEY PIT

3:    LEACHING OPERATION

Step 1: Determine groundwater exceeds relevant standards for Nonhazardous substances (Figure 1).

Step 2: Demonstrate that the nonhazardous substances causing the injury occur in the groundwater resource as a result of physical, biological, or chemical reactions resulting from or initiated by the release of hazardous substances [43 CFR § 11.62(c)(4)] (Figure 2).

1.   Hazardous Substances are Released from ARCO facilities:

   A.   Hazardous Metal/Metalloid Sulfides Occur in Waste Rock Piles, Tailings, Railroad Bed Fill, and Streamside Tailings

   B.   Sulfuric Acid and Ferric Sulfate Occur in Acid Mine Drainage

   C.   Sulfuric Acid was Added to Underground Workings and Waste Rock Piles for Leaching of Copper

2.   Hazardous and Nonhazardous Substances are Released as a Result of the Following Chemical and Biological Reactions that Result from or are Initiated by Releases of Hazardous Substances, (nonhazardous substances produced are underlined):

   A.   Direct Chemical Oxidation of Released Hazardous Metal Sulfides

   Oxygen, water, and ferric iron can oxidize hazardous metal/metalloid sulfides to produce dissolved hazardous metals and metalloids, iron, and sulfate, e.g.:

   $$CuFeS_2 + 7/2\ O_2 + H_2O \rightarrow Cu^{2+} + \underline{Fe^{2+}} + 2\underline{SO_4^{2-}} + 2H^+.$$

   $$CuFeS_2 + 14Fe^{3+} + 8H_2O \rightarrow Cu^{2+} + 15\underline{Fe^{2+}} + 2\underline{SO_4^{2-}} + 16\ H^+.$$
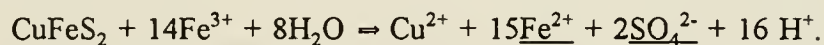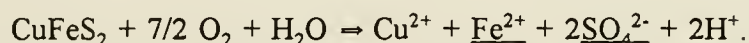
   B.   Direct Biological Oxidation of Released Hazardous Metal Sulfides

   Bacteria can attack some metal sulfides (MS) directly (including pyrite) and produce soluble metal sulfates (Olson, 1986), which dissolve to form dissolved metals (M) and sulfate:

   $$MS + 2O_2 \rightarrow MSO_4 \text{ (generalized formula)}$$

   $$MSO_4 + H_2O \rightarrow M^{2+} + \underline{SO_4^{2-}} + H_2O.$$
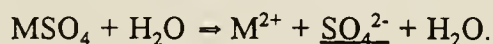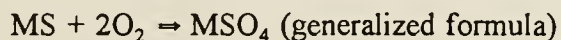
C.   Chemical Oxidation of Hazardous Substances by a Released Hazardous Substance

Ferric sulfate is a CERCLA hazardous substance [40 CFR § 302.4]. Acidic ferric sulfate $[Fe_2(SO_4)_3{}^0]$ in acid mine drainage can act as a powerful oxidant for dissolving other sulfides that contain heavy metals, for example for chalcopyrite:

$$CuFeS_2 + 2Fe_2(SO_4)_3{}^0 \rightarrow CuSO_4 + 5\underline{FeSO_4} + 2S^0.$$
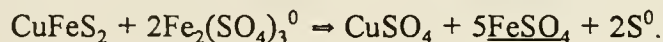
Other hazardous metal sulfides of zinc, lead, copper, cadmium, nickel, arsenic, cobalt, silver, and antimony can also be oxidized and dissolved by ferric sulfate to form dissolved heavy metals or metalloids and sulfate.

D.   Chemical Oxidation of Nonhazardous Substances by a Released Hazardous Substance

Acidic ferric sulfate in acid mine drainage can also oxidize pyrite, which contains iron and sulfur and is not a listed hazardous substance. The oxidation of pyrite by ferric sulfate produces dissolved iron and sulfate:

$$2FeS_2 + 2Fe_2(SO_4)_3{}^0 \rightarrow 6\underline{Fe}^{2+} + 6\underline{SO_4}_2. + 4S^0$$
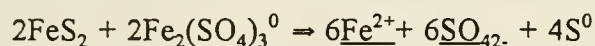
E.   Chemical Acid Dissolution of Nonhazardous Substances by a Released Hazardous Substance

Sulfuric acid is present in acid mine drainage, in the underground mine as a result of injection of sulfuric acid for extraction of copper, and in the solutions added to waste rock piles for the copper leaching operation. Sulfuric acid from these sources can dissolve pyrite, manganese sulfides and carbonates, and aluminosilicates to produce dissolved iron, manganese, aluminum, sulfate, fluoride, and other compounds (see Figure 2).

In a memo from Steve Larson and Remy Hennet of SSP&A to Bill Duffy, PMH&S, dated January 21, 1994 Re: NRDA; Montana v. ARCO; Ground-Water Issues; 1994 Litigations Support Tasks (Bates Stamp SSP000002242 — SSP000002250), ARCO consultants discuss the use of sulfate, iron, and manganese to define injury. In the memo, SSP&A state that "Although sulfate may not be a valid parameter to assess damage under NRDA rules, it is a fact that sulfate is generated by the reaction of oxygenated water with tailings materials. Some of the sulfate originating from the tailings has most likely impacted ground water." They conclude that "...in the Anaconda area, sulfate cannot be used as a parameter to determine impact from the tailings because of the occurrence of natural hydrothermal brines containing high concentrations of sulfate." There is nothing in the NRDA regulations that

states either explicitly or implicitly that a parameter cannot be used to determine impact or injury if it occurs naturally. Nearly all inorganic parameters occur naturally, including arsenic, cadmium, and other metals. The more relevant measure of whether these inorganic substances can be used to define injury is if they have a relevant water quality standard and if concentrations in groundwater exceed those standards.

SSP&A further state that "...it is a fact that these two metals (iron and manganese) are generated by the dissolution of diverse minerals in acidic solutions, and that acidic solutions result from the oxidation of tailings material by oxygenated water. Some dissolved iron and manganese most likely has been released from the tailings to ground water in the Anaconda area." In these statements, ARCO concedes that iron and manganese in groundwater originate, at least in part, from the leaching of mine waste. They conclude, however, that "...alluvial material in the Anaconda area is naturally rich in both iron and manganese..." Again, there is nothing in the NRDA regulations that prohibits the use of naturally-occurring substances as parameters to define injury. These substances do have relevant water quality standards that are exceeded in area groundwater, and their presence in groundwater is a result of the release of hazardous substances, as outlined in Figure 2.

3.0 LOCATION OF BUTTE BASELINE BEDROCK WELLS IN UNMINERALIZED OR MINERALIZED AREAS

A number of publications have discussed mineral zoning in the Butte area, including: Barnes (1979); Guilbert and Zeihen (1964); Sales (1913); Meyer et al. (1968); and SEG, USGS, and Anaconda Company (Miller 1973). The width of the Peripheral Zone, which is characterized by silver, gold, manganese, and zinc mineralization, is indefinite and irregular. However, arsenopyrite has been observed up to two miles or more from the central copper zone (Sales 1913). In the Hennet Report (1995), ARCO states that no baseline bedrock wells are representative of the Central Zone; six are representative of the Intermediate Zone (A, B, C, D-1, D-2, E); two or three are representative of the Peripheral Zone (F, Hebgen Park, 93-83); and the other fourteen control wells are in nonmineralized bedrock (pg. 11).

On Plate B1-1 in the Hennet Report, the outer edge of the Peripheral Zone is not defined, but silver veins are present south of Silver Bow Creek where granite (likely Butte Quartz Monzonite) outcrops. These silver veins are in the vicinity of a number of the DW and BMW wells that were previously thought to be in unmineralized areas (Hennet, 1995 using USGS, 1895). In fact, well DW-129 is located directly on a silver vein. Well DW-125 is located less than one-half mile to the east of the granite-alluvial border, and is also in the mineralized Peripheral Zone. Well DW-128 is located approximately 2,000 feet to the east of DW-129 and even closer to Butte Hill and is also in the mineralized Peripheral Zone. Similarly, wells BMW-5, BMW-1, BMW-13, and BMW-11, which are even closer to Butte Hill, are also in the mineralized Peripheral Zone. All of these wells are in weathered portions of the bedrock aquifer (Maest and Metesh, 1995, Appendix IID). The Tarkelson, Hall, Scott, and Johnson

wells are not on Hennet's Plate B1-1. However, the Johnson and Tarkelson wells were located on the Smedes (1967) map and are in mineralized areas. The Johnson Well is north of the Girl Scout Camp and is an area with small mineralized veins. The tarkelson well is on the east flank of the mineralized Timber Butte area, within 1/4 mile of a mineralized vein. The Hall and Scott wells were not located on any available geologic maps and can therefore not be assumed to be in mineralized areas.

The six Botz wells were also located on the Smedes (1967) geologic map. All of these wells or springs are in mineralized areas. Sample 31 CCB is in the mineralized Timber Butte area. Samples 25 CAD and 36 ADA are in the Little Basin Creek and Herman Gulch areas just north of the molybdenum property. Samples 06 BBB, 06 CBD and 27 CAD are also in mineralized areas in close proximity to mineralized veins. Therefore, based on new information provided by ARCO and other sources, 15 of the bedrock control wells previously thought to be in unmineralized areas are actually in mineralized portions of the Peripheral Zone or other mineralized areas. This brings the number of mineralized bedrock control wells to 27 out of a total of 32 bedrock control wells or springs.

4.0 LOCATION OF BASELINE BEDROCK WELLS IN THE CENTRAL ORE ZONE

As discussed above, ARCO states that none of the bedrock control wells are in the Central Ore Zone. Based on Plate B1-1 in the Hennet Report (1995), no bedrock control wells are in the Central Zone. The Central Zone and the Intermediate Zone were first described by Sales (1913), and are the areas of Butte Hill that contain copper ore. Sales describes the Central Zone as a copper zone of altered granite with ores that are characteristically free from sphalerite and manganese minerals, the Intermediate Zone as an area with ores that are predominantly copper but are seldom free from sphalerite, and the Peripheral Zone as the area in which copper has not been found in commercial quantities but that is characterized by vein fillings of rhodonite, sphalerite, pyrite, and rhodochrosite (Sales 1913).

Sales (1913) further states that the dividing lines between these three zones are arbitrary. The ratio of one copper mineral to another changes in the Intermediate Zone compared to the Central Zone, and there is an overall decrease in copper content but an increase in silver, zinc, lead, and manganese. However, the change consists mainly in the addition of sphalerite (zinc sulfide) (Sales 1913). Pyrite, which controls the formation of acid mine drainage, is present in roughly the same percentages in both the Intermediate and Central Zones but decreases on the edges of the Intermediate Zone and in the Peripheral Zone (Sales 1913). Therefore, the principal difference in mineralogy and mineralization occurs between the Intermediate and Peripheral Zones, not between the Central and Intermediate Zones. In fact, Meyer et al. (1968) emphasizes this difference by drawing the outer edge of the copper ore zone, which includes the Central and Intermediate Zones (Figure 3). The Intermediate Zone is distinguished from the Central Zone solely by the additional presence of sphalerite. According
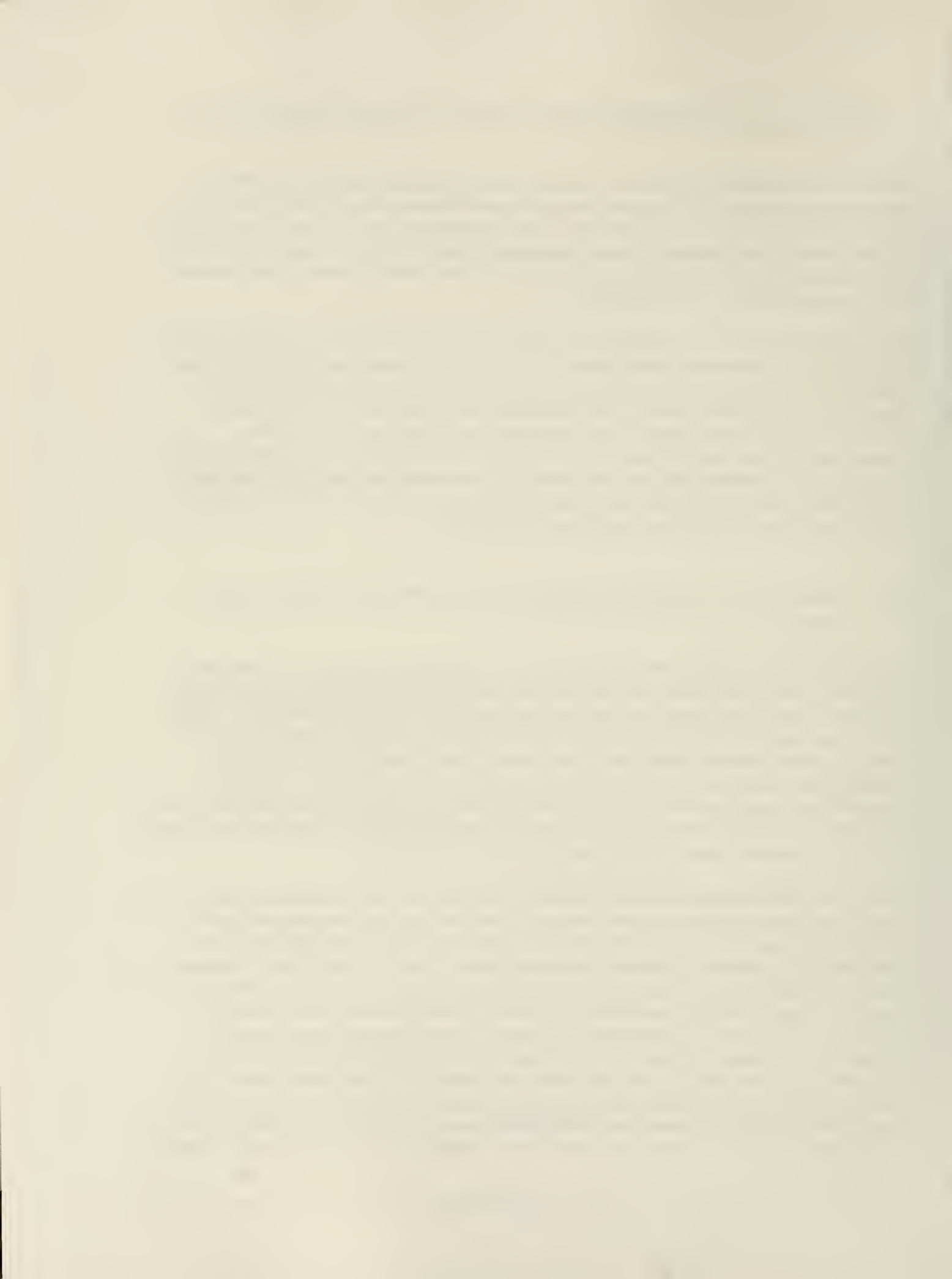
Figure 3
The Copper Zone
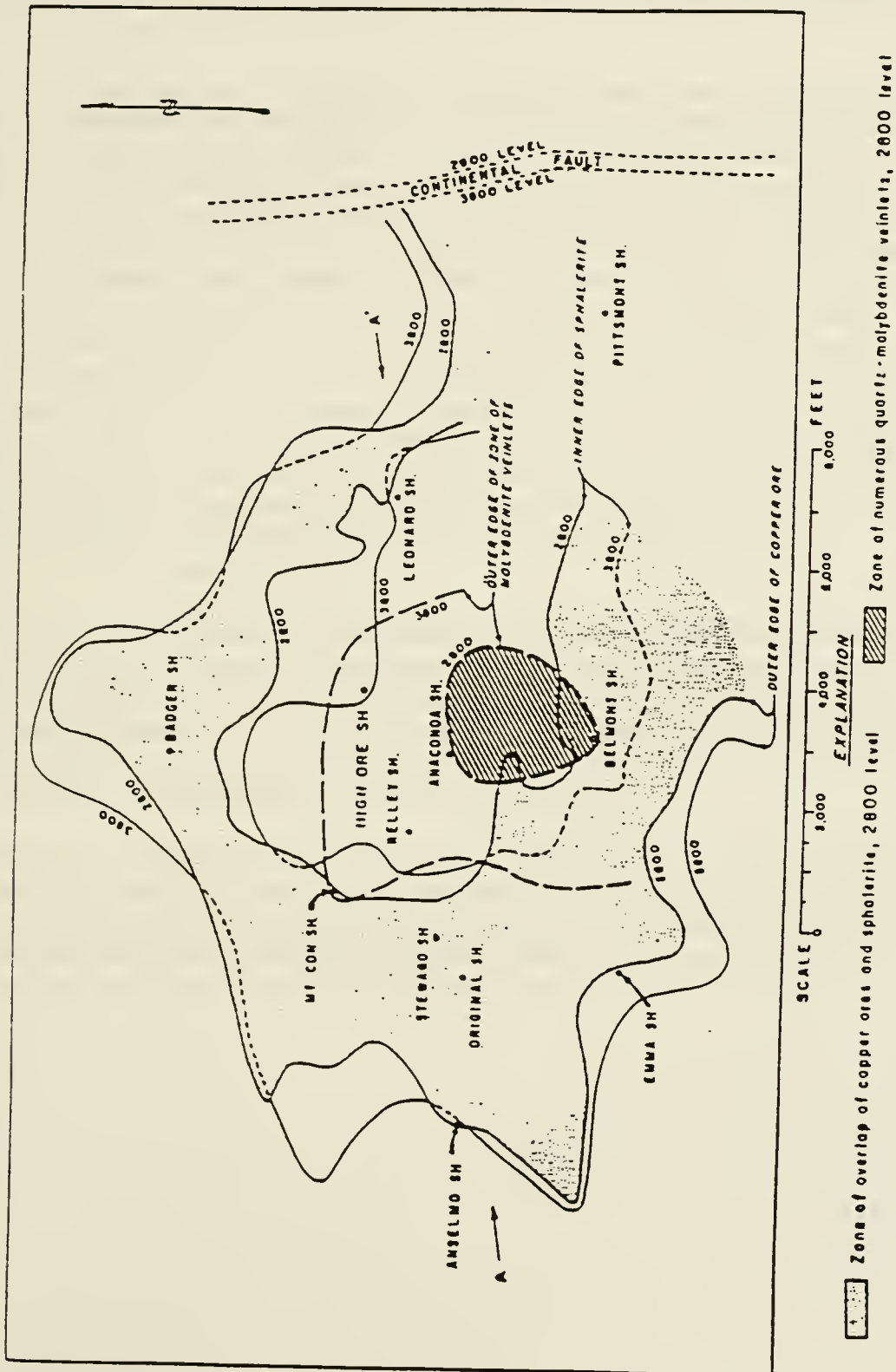
Source: Meyer et al., 1968.

to the Meyer et al. (1968) figure, baseline control wells A, B, C, D-1, D-2, E and possibly F are all in the copper zone.

In addition, the ore zonation refers to mineralogy, not to groundwater chemistry. Pre-mining groundwater flow directions were most likely from the Central Zone outward toward the Intermediate and Peripheral Zones. Therefore, groundwater moving through cracks and fissures in the Butte Hill mineralized bedrock would pick up the chemical signature of the Central Zone as it moved through it and into the Intermediate Zone. Taken as a whole, a distinction can be made between the Central and Intermediate Zones and the Peripheral Zones in terms of gross mineralogy, but, considering that the lines between these zones are arbitrary and that the zones do not reflect groundwater chemistry distinctions, the most important discrimination is between general mineralized and unmineralized locations. As discussed above, based on new information provided by ARCO and Smedes (1967), all but five of the baseline bedrock control wells or springs are in mineralized bedrock. A number of wells in the copper zone (A, B, C, D-1, D-2, E, and possibly F) are likely even influenced by mining, especially by increased exposure of pyrite to oxidation as a result of the lowered water table from dewatering activities (Maest and Metesh, 1995). These wells, therefore, likely overestimate concentrations of contaminants that would be present under pre-mining conditions in mineralized Butte Hill bedrock.

The medians, 25th and 75th percentiles, interquartile ranges, and Mann-Whitney p-values for the 27 mineralized bedrock baseline samples are shown in Table 1 (not all samples were analyzed for all parameters). No median concentration exceeds an MCL value; therefore, the mineralized baseline groundwater is potable (the antimony (Sb) value of 10.5 µg/L is equal to one-half the detection unit. All samples were below detection for antimony.). Only one median concentration, that for maganese, exceeds an SMCL value.

The Mann-Whitney p-values are for comparison of mineralized bedrock control and injured samples. Some substances do not have p-values because they were not determined in injured bedrock groundwater samples (see Maest and Metesh, 1995). All substances except for aluminum and chromium show a statistically significant difference (at a p-value of 0.05) between injured and mineralized baseline bedrock groundwater.

| | | | | | Table 1 | | |
| Median Concentrations, Percentiles, Interquartile Ranges, and p-Values of Substances in Mineralized Bedrock Control Wells (μg/L; SO_4 in mg/L) | | | | | | | |

	# Wells (n)	Median	25th Percentile	75th Percentile	Inter-Quartile Range	Mann-Whitney p-Value
Ag	14	1.96	0.5	3.47	2.97	0.0005
Al	15	24.5	15	74	59	0.47
As	20	3.52	2.15	10.66	8.51	0.003
Be	9	1	0.5 ˙	1	0.5	
Cd	20	1.02	0.45	1.6	1.15	0.0018
Cr	15	3.01	1.75	4	2.25	0.1611
Cu	20	8.5	2	16.5	14.5	0.0371
Fe	21	40	11	1,095	1,084	0.0035
Mn	17	218	4	1,555	1,551	0.0033
Ni	14	6.9	1	19	18	0.0005
pH	21	7	6.79	7.8	1.01	0.0003
Sb	3	10.5	10.5	10.5	0	
SO_4	27	242	65	372.5	307.5	0.0001
Tl	3	1	1	1	0	
V	8	38	3.1	61.5	58.4	
Zn	20	80.5	18	287.5	269.5	0.003
Zr	5	22	21	36.5	15.5	

5.0   USE OF MEINZER AND BOTZ DATA TO ESTIMATE BASELINE BEDROCK GROUNDWATER QUALITY

For the evaluation of baseline bedrock groundwater quality, six water quality samples from Botz (1969) and three water quality samples from Meinzer (1914) were used. However, the samples were only used for two purposes: to evaluate groundwater type (Pitzer plots on Figure 3-4, Maest and Metesh, 1995); and to determine baseline concentrations of sulfate, not metals, in bedrock groundwater (Maest and Metesh, 1995, Appendix IID). The six sulfate analyses in Botz (1969) were conducted by the Montana Bureau of Mines and Geology Water Quality Laboratory. The three sulfate analyses in Meinzer (1914) were conducted on samples from water supply wells.

Hennet (1995) claims that the State rejected other historic data describing poor quality groundwater (Weed 1912), yet the analyses by Weed were conducted on samples of mine water and cannot be considered to be background (Meinzer 1914, pg. 97; Weed 1912, pg.101). In addition, both Meinzer and Botz were/are groundwater scientists, while Weed was clearly a geologist and had no training in water science. Furthermore, analytical methods for sulfate have not changed substantially in at least 60 years (Sheen et al., 1935, as cited in APHA-AWWA-WPCF, 1980) and unlike analytical determination of trace metals, the accuracy of sulfate concentrations in natural waters has not been re-evaluated because of vastly improved methods of collection and analysis. Given that sulfate analytical methods have not changed for decades or longer, including historical sulfate analyses of nonmining impacted groundwater is acceptable practice for determining baseline concentrations of sulfate in bedrock groundwater. Considering that the Meinzer samples are at least 80 years old, the three Meinzer samples will be excluded from, but the six Botz samples will be included in, the list of baseline bedrock samples.

Removing the Meinzer sulfate analyses from the evaluation of bedrock baseline groundwater quality does not change the conclusion that mineralized bedrock groundwater was potable absent releases from mining activity at the site. When the three Meinzer samples are removed from the analysis, the median sulfate concentration for baseline bedrock groundwater is 190 mg/l (n = 29 wells). In addition, as discussed in the Butte groundwater report (Maest and Metesh, 1995), a number of the wells used for baseline bedrock analysis (A, B, C, D-1, D-2, E, F) are likely influenced by mining activity. When median sulfate concentrations in injured and baseline bedrock groundwater (excluding the Meinzer samples) are compared using the Mann-Whitney rank sum test, there is a statistically significant difference between median sulfate concentrations, as shown in Table 2.

Table 2
Statistical Comparison of Sulfate Concentrations (mg/l) in Baseline
and Injured Bedrock Groundwater, Butte Area, without Meinzer Samples

	Baseline (n = 29)	Injured (n = 11)
Median Concentration	190	948
25th Percentile	65	627
75th Percentile	340	2,050
Interquartile Range	275	1,423
Mann-Whitney p-Value	0.0001	0.0001

As shown in Table 2, the exclusion of the Meinzer sulfate analyses does not affect conclusions about either the potability of baseline bedrock groundwater or the statistically significant differences between sulfate concentrations in baseline and injured bedrock groundwater in the Butte area.

6.0 ARCO'S USE OF GEOCHEMICAL MODELING TO DETERMINE CONCENTRATIONS OF CONTAMINANTS IN MINERALIZED BEDROCK GROUNDWATER

Very little background information is provided in the Hennet report or in discovery materials on the methods used to predict mineralized background groundwater quality using geochemical modeling. A memo from Dimitri Vlassopoulos (SSP&A) to SSP-230 dated August 12, 1994 (Bates Stamp SSP000003621) indicates that he followed the methods used by Runnells and others (1992), but no list of reference citations is provided.

It appears that 'forward' geochemical modeling was used to predict the concentrations of metals and other substances that would result from the weathering of different mineral assemblages. In order for forward geochemical modeling results to be calibrated and verified or validated, the modeling results must be compared to water chemistry data from actual water samples collected in a similar geochemical environment. SSP&A did not perform any comparison of their results to samples of baseline bedrock groundwater to determine if their modeling effort was a good approximation of reality. The fact that no groundwater currently exists in the weathered Central Ore Zone of the Butte Hill bedrock aquifer does not indicate that geochemical modeling should be conducted. Quite the contrary, it demonstrates that the
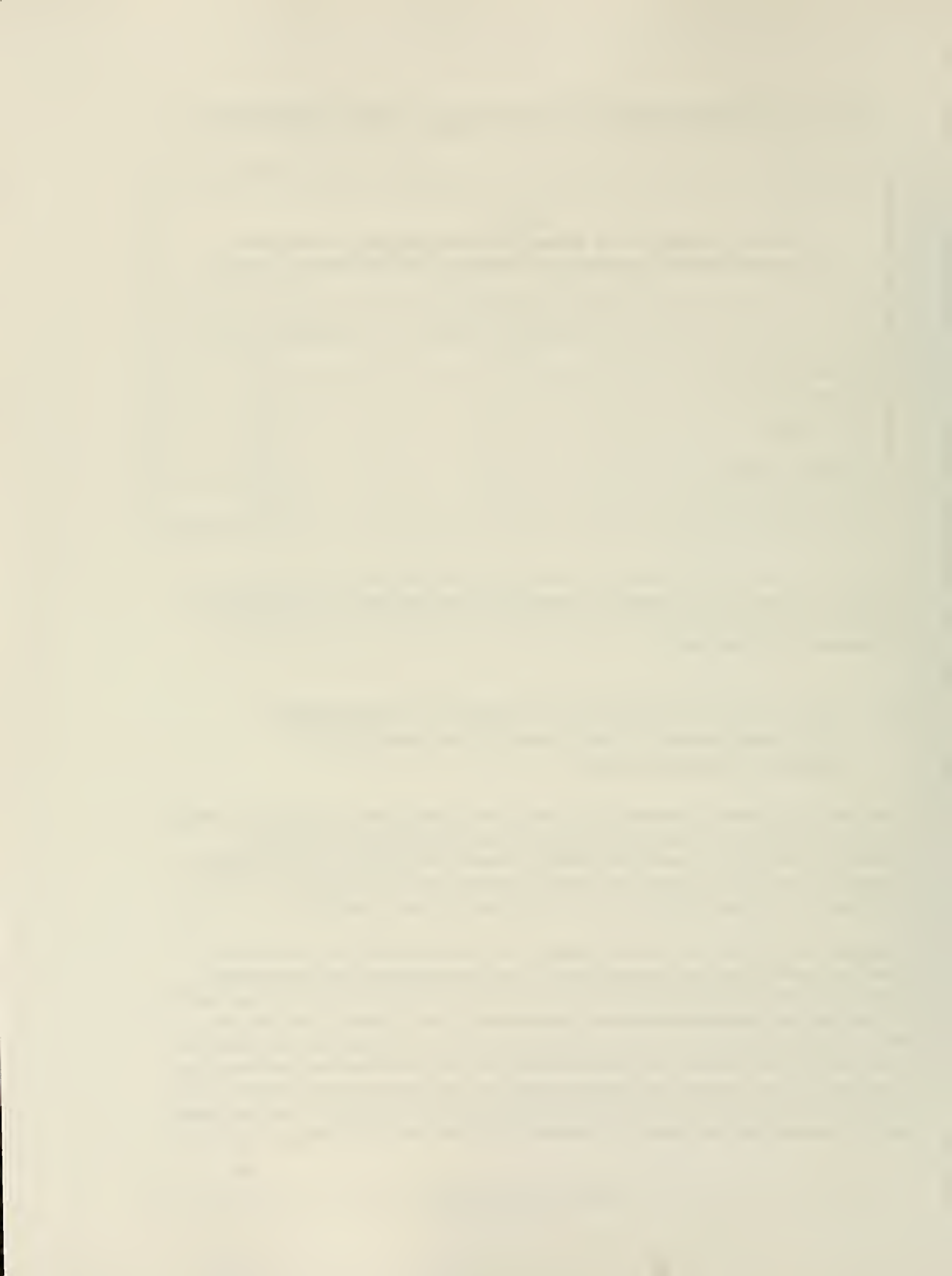
results of forward geochemical modeling cannot be trusted because the results can never be calibrated or verified.

Runnells et al. (1992) state that predictive geochemical modeling can put realistic *upper limits* on the concentrations of chemical components to be expected in natural waters at equilibrium with rock and ore minerals. The authors further state that the goal of simulations is simply to determine if it is chemically possible to release significant concentrations of dissolved metals, and that equilibrium geochemical modeling (as presented in their paper) represents only a first approximation to the real situation. Runnells et al. (1992) also state that the main limitations of predictive geochemical modeling are: solid phase choices must be representative of the ore or rock being modeled; Eh and pCO_2 must be representative of the geochemical environment being modeled; and the chemical equilibrium assumption will generally overestimate concentrations of metals. It appears that all three limitations are relevant when Hennet's modeling effort is examined in more detail.

Hennet indicates in his report (Appendix B1) that his six zones are based on available descriptions in Guilbert and Zeihen (1964). However, there are many discrepancies between the minerals listed in Guilbert and Zeihen for these zones and those listed in Hennet's Table B1-2. The numerous discrepancies demonstrate that the solid phases chosen for the modeling are not representative of reality. The discrepancies are as follows: Zone 1: Guilbert and Zeihen (G&Z) list only quartz, pyrite, enargite, and chalcocite as the main minerals (listed as "very abundant, abundant, common, or minor" in G&Z), while Hennet lists those plus kaolinite, muscovite, and calcite. Zone 2: G&Z list only quartz, pyrite, enargite, chalcocite, chalcopyrite, calcite, and dolomite as the main minerals, while Hennet doesn't include chalcopyrite but does add kaolinite, muscovite and rhodochrosite. Zone 3: G&Z list only quartz, calcite, dolomite, rhodochrosite, pyrite, sphalerite, rhodonite, chalcopyrite, and galena as the main minerals, while Hennet does not list rhodonite but does add kaolinite, muscovite, and greenockite. Hennet's Zone 4 does not exist in Guilbert and Zeihen. Zone 5: G&Z list only kaolinite, chalcocite, and chalcanthite as the main minerals, while Hennet adds quartz, muscovite, goethite, gypsum, and anglesite (anglesite is not even on the G&Z list in their Table 6). Zone 6: G&Z list halloysite, chrysocolla, tenorite, and cuprite as the main minerals, while Hennet adds muscovite, goethite, cerussite, smithsonite, and malachite.

In G&Z's discussion of their supergene + pyrite zone, which applies to the Berkeley pit area (Hennet's Zone 5), minerals resulting from mining activity are also included, which have "markedly increased the abundance of iron oxides and mixed iron-copper sulfates in the pit ores" (Guilbert and Zeihen 1964, pg.12). Therefore, the mineralogy of this zone should not be used to predict pre-mining water chemistry. The same holds true for the supergene - pyrite zone (Hennet's Zone 6), which applies to the mined Continental Pit. In addition, not enough information is provided in the Hennet report or in discovery materials to determine if the relative abundance of the chosen minerals used by Hennet in the predictive modeling is representative of reality.
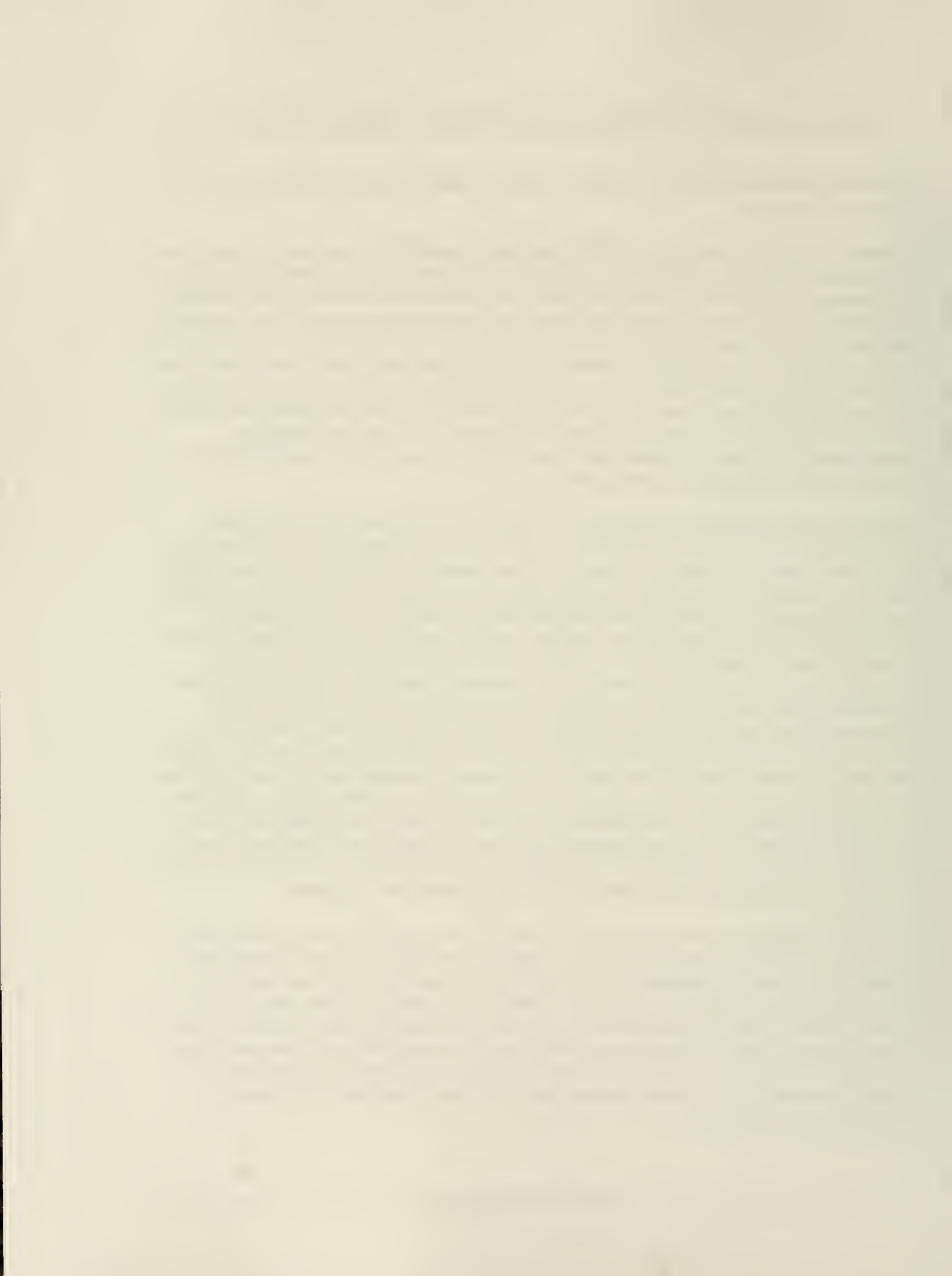
The one exceedence of a primary drinking water standard (lead in Hennet's Zone 5) is due to the presence of a mineral (anglesite, a lead sulfate) that is not even listed in Guilbert and Zeihen's Table 6 or in the text. Similarly, the exceedence of the lead standard in Hennet's Zone 6 (G&Z's supergene - pyrite zone, which applies to the Continental pit area) is due to the presence of the mineral cerussite (a lead carbonate), which is indicated as being present in only trace amounts ("infrequently encountered") in G&Z's Table 6. As discussed above, the mineralogy of both of these zones is only relevant for mining impacted areas, not for baseline determination.

One of the biggest problems with Hennet's predictive modeling is the assumption that "veins and mineralized fissures form preferential pathways for groundwater flow, and that the groundwater quality is determined by the minerals present in the veins and in the hydrothermally altered wall rocks adjacent to the veins" (Hennet report, Appendix B1). The implication in this statement is that neither the alteration halos around the veins or the Butte quartz monzonite itself affect the water chemistry of the bedrock groundwater. Hennet does make some attempt to include the mineralogy of the alteration halos by including kaolinite and muscovite. However, the mineralogy of the alteration halos around the veins is included in Guilbert and Zeihen (1964) and could have been easily included in the geochemical modeling effort. The method used by Hennet excludes the halos and unaltered Butte quartz monzonite. This exclusion will overestimate concentrations of contaminants in mineralized baseline groundwater because no "dilution" is provided by weathering of the alteration halos and the monzonite. The alternation halos and the monzonite are abundant and riddled with fractures from natural faulting and man-induced blasting fractures and thus provide ample pathways for transport of contaminants through the bedrock aquifer.

Finally, in Hennet's discussion of attenuation of metals in Anaconda groundwater(Appendix B5) he relies heavily on adsorption reactions to arrive at final concentrations of contaminants in alluvial groundwater. Apparently, adsorption was not considered in the predictive geochemical modeling of bedrock groundwater quality. Consideration of adsorption in the geochemical modeling would reduce concentrations of contaminants in the Butte bedrock groundwater. Minerals considered to be present in Butte bedrock groundwater (whether they were or not) were assumed to be dissolved in equilibrium concentrations, which, as indicated in the Runnells et al. (1992) paper, will yield *maximum* concentrations of metals in waters.

Geochemical modeling does provide interesting information that can be used to predict what maximum baseline contaminant concentrations might be under idealized conditions that exist only infrequently. Even under these idealized conditions, geochemical modeling results, especially from forward geochemical modeling, are meaningless unless they can be compared to concentrations in actual water samples. Rather than face the myriad problems associated with predictive geochemical modeling, the State has chosen to use available water quality data from mineralized areas in the bedrock aquifer to estimate what concentrations of contaminants would be absent the release of mining-related hazardous and related substances in the Butte area. As discussed in Maest and Metesh (1995) and in this rebuttal report, the
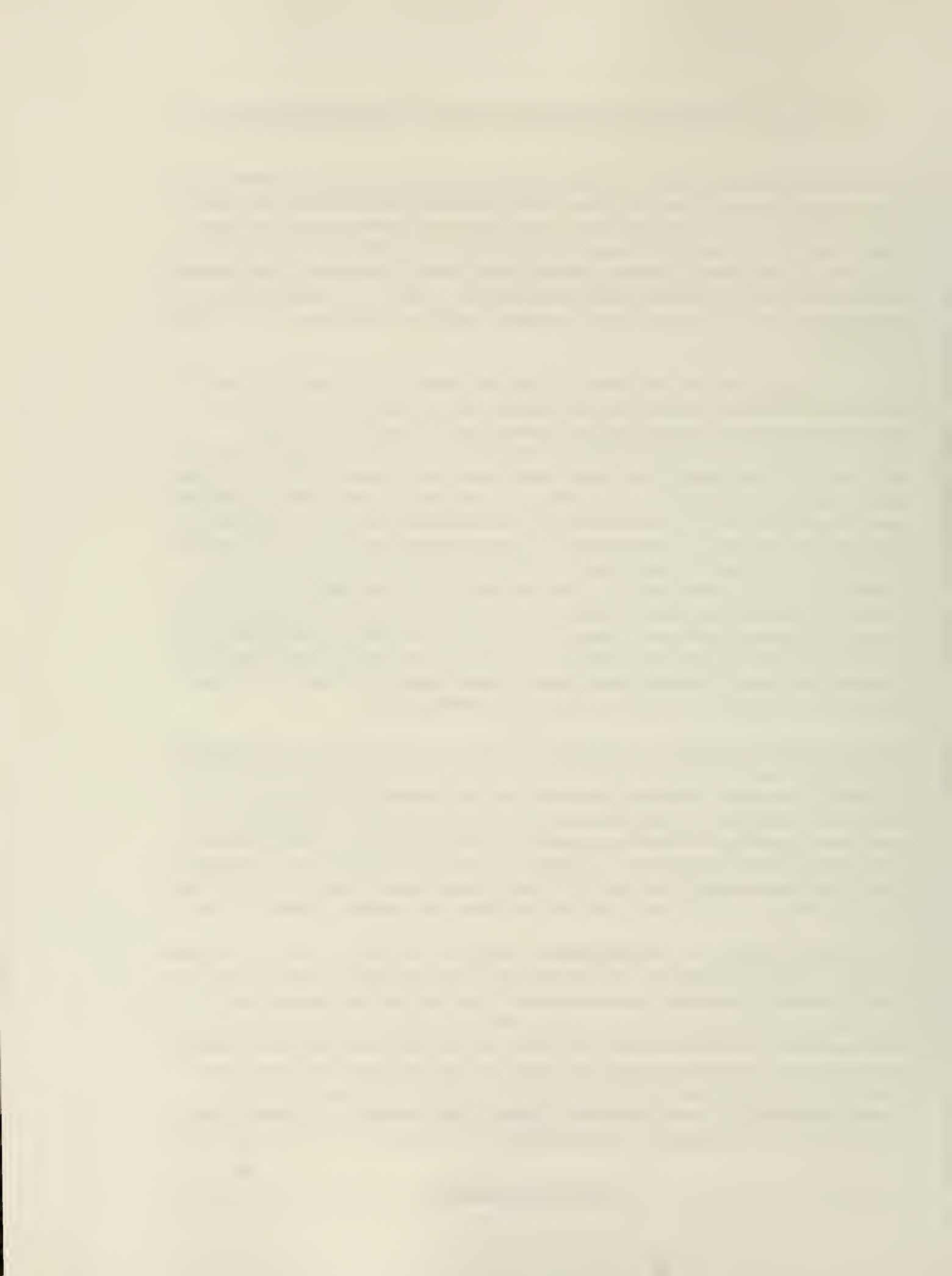
choice of samples used by the State to determine baseline bedrock groundwater concentrations is representative of mineralized conditions in the bedrock aquifer and even includes samples that are likely impacted by mining activity (dewatering, blasting, and use of sulfuric acid in the underground mine). The resultant concentrations of contaminants in baseline bedrock groundwater do not exceed any MCL values and demonstrate that groundwater in the bedrock aquifer was potable absent mining-related releases in the Butte area.

7.0 BASELINE CONCENTRATIONS OF NITRATE IN THE AREA I ALLUVIAL AQUIFER

One sample from the alluvial baseline wells in Area I (MF-04) has a nitrate concentration that exceeds the nitrate maximum contaminant level (MCL) of 10 mg/l (as N). In addition to this nitrate MCL exceedence, one or more samples from the following injured wells in Area I also have nitrate concentrations that exceed the MCL: GS-33, GS-35S, GS-43S, GS-45, GS-46D, and DW-02. One well in the Butte Hill alluvial aquifer injured area also has a nitrate exceedence: LP-07. However, the exceedence occurs in only one sample where a triplicate was taken; the other two samples in the triplicate had nitrate concentrations of <1.0 and 1.0 mg/l, so the 10 mg/l nitrate analysis from this well is in question. In the injured bedrock groundwater, one sample from the Travona shaft had a nitrate concentration of 10.7 mg/l; however, all other analyses of Travona shaft water samples showed nitrate concentrations below 3.8 mg/l. Similarly, one sample from the Belmont shaft had a nitrate exceedence (11.1 mg/l); however, all other nitrate concentrations from Belmont samples were less than 4.8 mg/l. Therefore, blasting does not seem to be a source of nitrate in the Butte area.

One exceedence of nitrate in the Area I alluvial aquifer control wells does not demonstrate that groundwater in the alluvial aquifer was not potable absent mining-related releases. In fact, the median concentration of nitrate in the alluvial aquifer control wells is only 1.45 mg/l. The results of statistical analyses of nitrate values in baseline, Area I, and Butte Hill alluvial groundwater are listed in Table 3.

No median nitrate concentration exceeds the MCL value. When median values in the control and injured alluvial aquifer wells are compared, there is not a statistically significant difference for either the baseline-Area I comparison or the baseline-Butte Hill comparison. This further indicates that nitrate is not a player in terms of contamination of the alluvial aquifer.

8.0 SOURCES OF SULFATE IN THE ANACONDA AREA ALLUVIAL AQUIFER — POSSIBLE INFLUENCE OF GEOTHERMAL SULFATE

The results of an isotope study conducted by ARCO and its consultants are presented as Appendix B2 in the Hennet report (1995). No information is provided on methods used to

	Baseline (n = 6)	Injured Area I (n = 81)	Injured Butte Hill (n = 15)
Table 3 **Statistical Comparison of Nitrate Concentrations (mg/l) in Baseline and Injured Alluvial Groundwater**			
Median Concentration	1.45	1.15	3.0
25th Percentile	0.05	0.03	0.82
75th Percentile	6.06	4.3	4.45
Interquartile Range	6.01	4.3	3.63
Mann-Whitney p-value		0.64 (Baseline/Area I)	0.59 (Baseline/Butte Hill)

collect water samples, methods used to preserve water samples, and methods used to analyze samples for sulfur, oxygen, and hydrogen isotopes. It is not clear, for example, if the sulfur, oxygen, and hydrogen isotope values presented are for sulfate, sulfide, and/or water. If the isotope values are not for dissolved sulfate, the study is meaningless, because the purpose of the study is to address the possible sources of sulfate (not sulfide or water) in a variety of groundwaters in the Anaconda area. It cannot be assumed that there is isotopic equilibrium between sulfate and sulfide, because the kinetics of isotope equilibrium is quite slow at low temperatures (Pearson and Rightmire 1980). Almost no text is provided to describe the study design or to aid in interpretation of the data presented. The State can only make the assumption at this point that the sulfur and oxygen isotope values presented are for dissolved sulfate.

Generally, $\delta^{34}S$ is enriched in oxidized sulfur species and minerals and depleted in reduced sulfur species and minerals. Consequently, sulfate derived from the dissolution of evaporite minerals, which may include metal sulfates in efflorescent crusts, would tend to have higher $\delta^{34}S$ values, while sulfate derived from the oxidation of pyrite, other sulfides, organic sulfide, and sulphur in coal and oil would have lower $\delta^{34}S$ values (Pearson and Rightmire 1980). ARCO assumes that the two relevant end-members for $\delta^{34}S$ values is tailings water on the low end ($\delta^{34}S$ ranges from -5.3 to 3.1 per mil CDT) and geothermal waters on the high end ($\delta^{34}S$ ranges from 15.8 to 21.8 per mil CDT in the Anaconda area). ARCO further assumes that the $\delta^{34}S$ values in the "wells in the Anaconda area" (Table B2-1, Hennet report) are intermediate in value and derive from the mixing of tailings and geothermal waters. Another

possible explanation for the observed $\delta^{34}S$ values is that the sulfate in the Anaconda background and monitoring wells derives from dissolution of sulfate minerals, possibly a combination of naturally-occurring sulfates such as gypsum and metal-rich sulfates in mining-related efflorescent crusts. However, whatever the explanation, the fact that the background and injured wells in the Anaconda area have very similar $\delta^{34}S$ values, as discussed below, indicates that the same processes are going on in the background and injured wells and that those processes have been accounted for and are reflected in baseline sulfate concentrations in the Anaconda area.

ARCO does not separate out background and injured wells in Table B2-1 in Appendix B2 (Hennet 1995). However, in some of the discovery material they did separate out background wells from other monitoring wells (a table labeled "Butte-Anaconda Isotope Data, 10/12/94, Bates Stamp SSP000000858). A number of graphs are also provided on which data from background and injured monitoring wells in the Anaconda area are plotted separately. An example is provided in Figure 4, where $\delta^{34}S$ is plotted against sulfate concentration. As shown in the plot, the range of $\delta^{34}S$ values in samples from monitoring wells and background wells is very similar. The upper range of $\delta^{34}S$ values for the background wells also encompasses the highest $\delta^{34}S$ values from geothermal waters. This similarity in range of $\delta^{34}S$ values between baseline and injured samples strongly indicates that whatever processes are occurring in the injured wells in the Anaconda area are also occurring in the background wells. Therefore, if geothermal sulfate is impacting the concentration of sulfate in the injured wells, it is similarly impacting sulfate concentrations in the background wells.

We performed statistical analyses on data provided in Hennet's Appendix B2 and the table referred to above (Bates stamp SSP000000858). Three different sample types were compared: geothermal, injured, and background. All geothermal samples from Hennet's Appendix B2 were used. For the injured wells, well MW212 was excluded from the injured wells because it is a baseline well (Woessner 1995). Three wells identified as background in the Hennet appendix were inside the State's injured plume (Well-04, ANI-3, and ANI-5; Woessner 1995) and were therefore included in the injured wells for the statistical analyses. All of the wells identified as background, except for these three wells, were included in the background wells for the statistical analyses. There were 20 repeat measurements in the Hennet Appendix B2; repeat measurements were averaged to obtain a single value for each well site. Apparently, Hennet used the first of each measurement for a well instead of averaging the repeat measurements. The variability between repeat measurement was relatively small, so the method for handling repeat measurement should have little impact on the final statistical results. After averaging over repeat measurements, there were 46 separate wells consisting of 8 geothermal, 25 injured, and 13 baseline wells. However, $\delta^{34}S$ measurements were actually available for only 43 of these 46 wells (8 geothermal, 25 injured, and 10 background). Figure 5 plots $\delta^{34}S$ values for the three well types (geothermal, injured, and baseline). There is no overlap in the range of sulfur isotope signatures for the geothermal well samples and the injured well samples. Overall, $\delta^{34}S$ values for the baseline wells tend to be higher than those for the injured area, and it appears that one of the baseline wells (Well-03, shown to be in a

wetland in the headwaters of Lost Creek, Plate B2-2 in the Hennet Report) may be in a location where there is substantial geothermal influence, according to Hennet's interpretation of δ^{34}S values.

Assessment of the statistical significance of the differences between pairs of medians is provided in Tables 4 and 5. The results show that there is a statistically significant difference in sulfur isotope signatures between geothermal and either injured or baseline wells. However, there is no statistically significant difference in sulfur isotope signatures when baseline and injured wells are compared. It is therefore concluded that the background wells reflect at least as much geothermal influence as the injured wells. It also appears that the injured well samples have a highly significantly different sulfur isotope signature than samples from geothermal wells. The "geothermal" sulfate, then, is included in both the injured and background wells in the Anaconda area.

Table 4
Statistical Analysis of Anaconda Well Samples
(δ^{34}S, per mil CDT)

Source Area	# Wells	Range	Median	25th %ile	75th %ile	Inter-quartile Range
Geothermal	8	15.8-24.2	20.6	18.6	21.7	3.1
Injured	25	1.8-14.3	4.7	3.8	7.5	3.7
Baseline	10	2.8-21.3	8.9	6.3	14.5	8.2

Table 5
Two-Sided p-Values, Mann-Whitney Test

	Geothermal	Injured	Baseline
Geothermal	—	0.0001	0.0014
Injured	0.0001	—	0.0466
Baseline	0.0014	0.0466	—

In a memo from Remy Hennet and Steve Larson (SSP&A) to Bill Duffy dated September 1, 1993, SSP&A states that the isotope study would test the hypothesis that hydrothermal sulfate is present in groundwater at depths of more than about 20 feet and at shallow depth in close proximity to warm/hot springs in the Anaconda area. Based on this hypothesis, the presence of elevated sulfate concentrations at depths <20 feet and not in the vicinity of hot springs would then not be related to geothermal activity. As shown in Figure 6, which plots mid-screen well depth of injured wells in Anaconda against measured $\delta^{34}S$ values, there is no clear relationship between sulfur isotope values and depth. In fact, the deepest well has a sulfur isotope signature that is more representative of what Hennet is calling the tailings end-member, rather that of the higher sulfur isotope signatures for his geothermal end-member.

Finally, the close association of the sulfate plume in the Anaconda area with known areas of mining activity makes it most likely that the observed sulfate plume is a result of leaching from mine waste deposits and transport in the subsurface in the direction of groundwater flow.

9.0   POSSIBLE ATTENUATION OF ANACONDA GROUNDWATER PLUMES

The potential of Anaconda alluvium (beneath and downgradient of the Opportunity Ponds) to attenuate hazardous substances was addressed by ARCO in the Hennet report (pg. 23-25; Appendixes B3 and B5). As was true for the geochemical modeling and isotope studies discussed above, very little supporting documentation was provided for the "attenuation" studies in either the Hennet report or in discovery materials. In Appendix B3, the mineralogy of several cores from beneath Opportunity Ponds was investigated (locations identified on Plate B3-1 in the Hennet report). Appendix B5 presents the results of a geochemical modeling study on the potential attenuation of contaminants in Anaconda alluvium.

The results of the x-ray diffraction (XRD) mineralogical investigation are presented in Appendix B3 in the form of a letter from Dr. John Armstrong of the California Institute of Technology and in a summary table (Table B3-6). In the letter from Armstrong, the major phases observed in all specimens by XRD were quartz, potassium feldspar, albite, calcite, dolomite, muscovite, biotite, illite (and other clays). In Table B3-6 in the Hennet report, goethite is identified as "abundant" in sample GPC-02 and "suspected" in eight other samples, even though it is not mentioned as a major phase in any sample in the letter from Armstrong. The letter from Dr. Armstrong also references the results of identification of phases, sizes, and shapes of particles examined by SEM-EDS, but those results were not included in Appendix B3. Dr. Armstrong does state that iron oxide phases were "abundant, particularly as submicrometer rounded or spherical particles agglomerating onto the surface of larger particles." However, if the iron oxide is coating the surface of neutralizing minerals such as calcite, the neutralizing ability of the alluvium will be diminished. In Table B3-7 in Appendix B3, iron oxyhydroxides are listed as "secondary coatings" identified by SEM

Figure 4
δ^{34}S vs. Sulfate, Anaconda Area Wells

STABLE SULFUR ISOTOPE RATIO AND SULFATE
IN VARIOUS WATERS, ANACONDA AREA
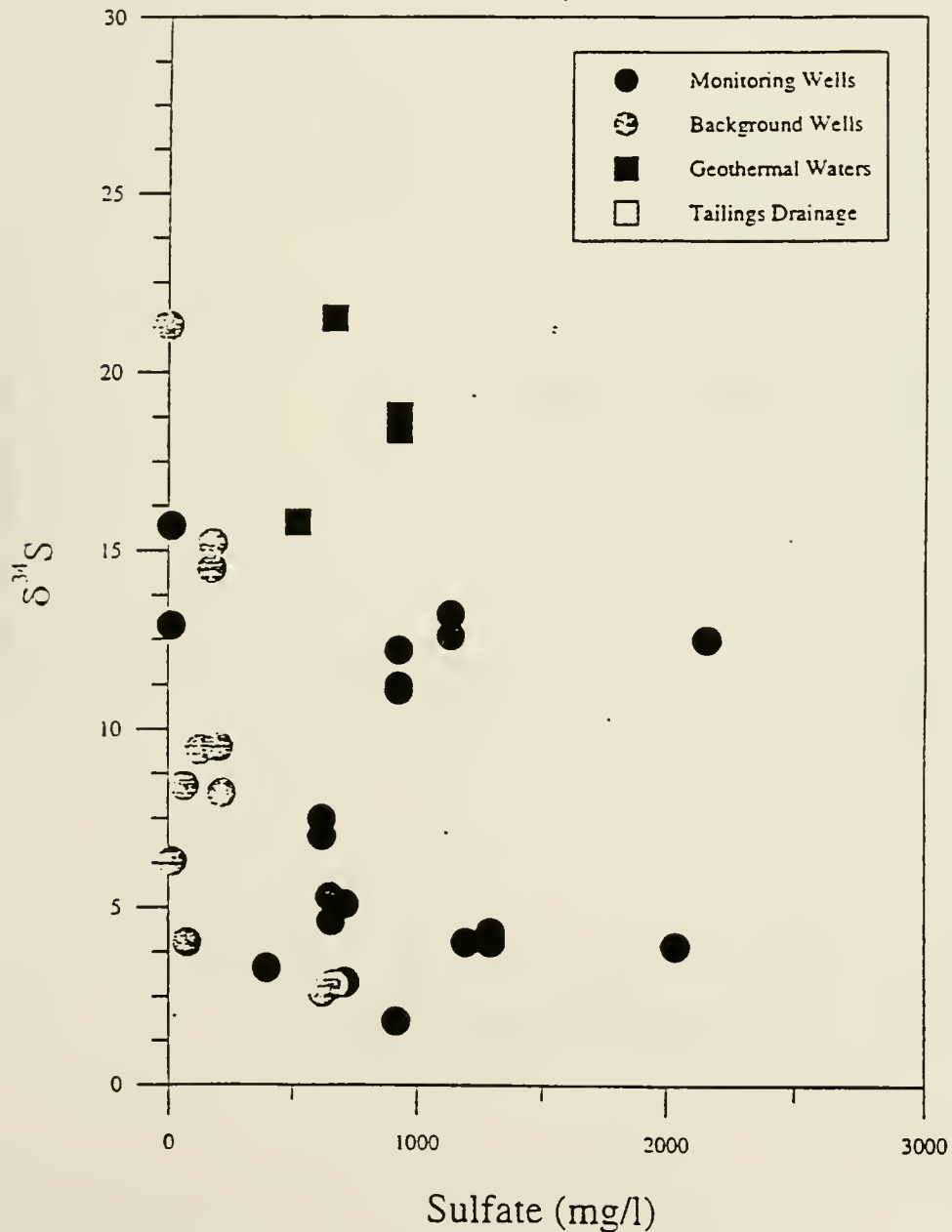
Source: Hennet Discovery Materials

Figure 5
Distribution of δ^{34}S Values for Geothermal, Injured, and Baseline Waters in the Anaconda Area
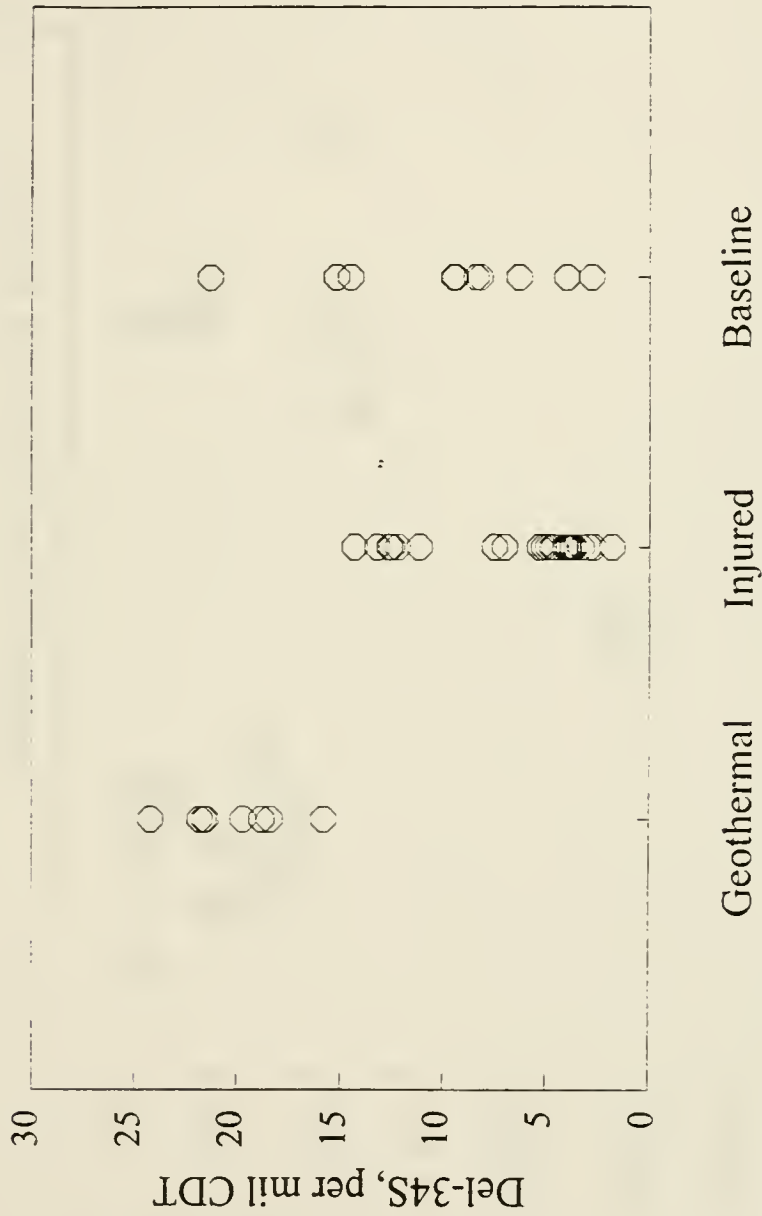
Figure 6
Mid-Screen Depth vs δ^{34}S Values, Injured
Anaconda Area Wells

Del-34S vs. Depth

Anaconda Injured Wells
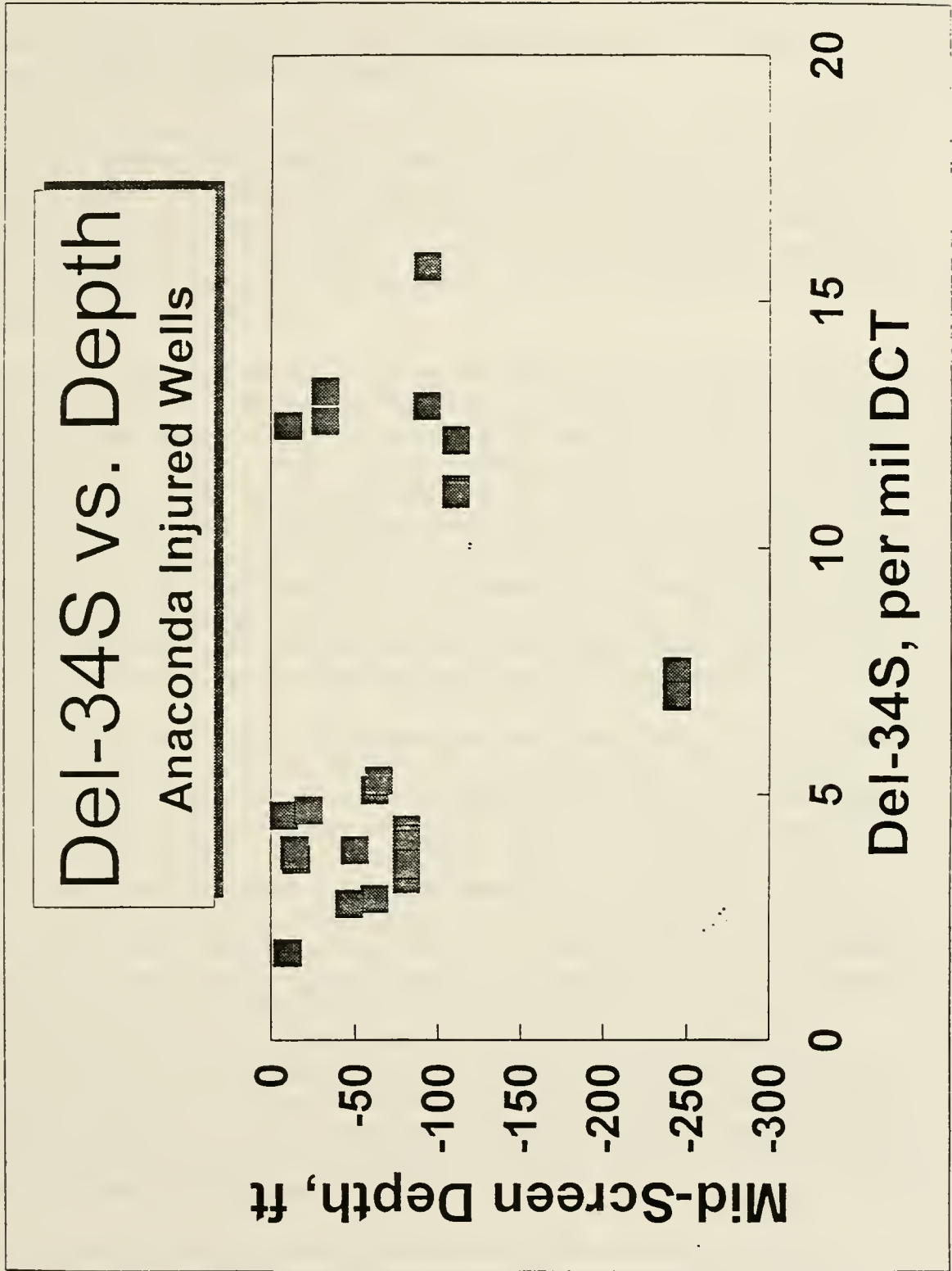
particle analysis. In Appendix B5, iron oxyhydroxides are characterized as "present ubiquitously as coatings on the matrix minerals.

The results of the attenuation/modeling study are nearly impossible to evaluate or interpret because so little supporting documentation is provided. It appears, based on the scant information in Appendix B5 and discovery materials, that three scenarios were modeled: no future infiltration through the tailings material (lowered groundwater mounding); limited infiltration of tailings leachate to groundwater (considered "most realistic"); and maximum infiltration of leachate through the tailings to groundwater. Input and output files were found for only the first and last scenario.

For the "no future infiltration" scenario, it appears that MINTEQA2 was used to simulate adsorption of contaminants in the impacted alluvial aquifer groundwater (see Table B5-1, Appendix B5, Hennet report). No pH was reported for this analysis, but a pH of 7 was used in the modeling effort. If the actual pH of the groundwater was lower, less adsorption onto aquifer materials would occur, and less iron (and most other metals) would precipitate out of solution. If the pH was higher, more adsorption would occur, but arsenic would also be more mobile. The concentrations reported in Hennet Table B5-1 do not match concentrations in the Tetra Tech appendix (Tetra Tech 1986, pg. C-7) . A number of the concentrations in the Tetra Tech appendix (collected on April 26, year unknown) were higher than those listed in Table B5-1. For example, calcium, silica, sulfate, iron, manganese, arsenic, copper, and zinc concentrations are higher in the Tetra Tech appendix than in the Hennet appendix.

For the "no future infiltration" scenario, it appears that ferrihydrite, calcite, and rhodochrosite were allowed to precipitate in the MINTEQA2 run and were possibly used as adsorbents (although this is unclear). Using arsenic as an example, the concentration is predicted to drop from 870 μg/l to 0.014 μg/l, just through adsorption onto aquifer materials. However, this water sample is in the alluvium and has already been subjected to adsorption onto aquifer materials. Clearly, some precipitation, dilution, and adsorption have already taken place, because concentrations are much lower than those in tailings samples. ARCO does not state how much farther downgradient the modeling effort for "no future infiltration" is simulating, but it appears that "extra" adsorbents were added (possibly ferrihydrite, calcite, rhodochrosite) that may not be characteristic of the character or quantity of adsorbents in the Anaconda alluvial aquifer. In addition, the iron oxyhydroxides in the alluvium downgradient of Opportunity Ponds contain heavy metals (Tetra Tech 1986), which may affect the absorption properties of the material. If this heavy metal-iron oxyhydroxide dissolves, which may occur under reducing conditions, the heavy metals would be released back into alluvial groundwater, and groundwater concentrations of these contaminants would increase. This possibility was not addressed in the Hennet modeling effort.

No modeling input or output files could be found for the "limited leachate infiltration" scenario. It appears that the starting composition was that shown in Table B5-1 for Well 89

(impacted alluvial aquifer groundwater), and this groundwater was possibly diluted with the baseline alluvial aquifer groundwater composition shown in Table B5-1. In this scenario, arsenic concentrations are predicted to drop from 870 μg/l to 0.08 μg/l. Again, it is not clear how far downgradient this decrease would be expected to occur, or how the model runs with PHREEQE were conducted. Therefore, the accuracy of the results shown in Table B5-3 cannot be established. In addition, and this is true for all the scenarios, results were not compared to any actual groundwater samples or experimental adsorption/dilution studies. Consequently, the modeling results were not calibrated or validated. This lack of calibration was also evident in the geochemical modeling effort to predict baseline concentrations in the bedrock aquifer (discussed above). Absent calibration of modeling results using results from actual water samples, the results of the modeling effort cannot be considered to represent reality.

In the final scenario ("maximum infiltration"), Hennet concedes that a groundwater plume could form. Clearly, a groundwater plume does exist under the ponds in the Anaconda area, so this is not a surprising conclusion and did not need to be confirmed using geochemical modeling, which may not approximate reality. It appears that two sub-scenarios were examined in the modeling effort: 25m downgradient and 50m downgradient. Both were modeled at 50 years into the future. Output from PHREEQE was used as input for MINTEQA2, presumably to simulate adsorption using the diffuse adsorption model with one adsorbing surface. Even though Hennet states that MCL and SMCL exceedences could occur, the results shown in Table B5-4 only show exceedences of the cadmium MCL and the sulfate proposed MCL. However, the arsenic MCL is exceeded in the alluvial aquifer groundwater at the present time. Therefore, it can be concluded that the modeling effort for this scenario does not do a good job of approximating reality.

The results from the Hennet attenuation study discussed above are in direct conflict with results from the Tetra Tech geochemistry report (Tetra Tech 1986), which was conducted for Anaconda Minerals Company. Tetra Tech predicts that the groundwater mounding will decrease over approximately 30 years, and that the oxidizing zone will slowly move downward (over 10,000-20,000 years) until it reaches the bottom of the tailings material. As the oxidizing zone moves downward, sulfate is predicted to move into the groundwater, but arsenic is predicted to precipitate as a sulfide in the reduced zone. However, when the oxidizing zone reaches the bottom of the tailings, arsenic concentrations are predicted to be higher than present concentrations, not lower, as predicted by Hennet. The discrepancy may be related in part to the shorter time frame used by Hennet (50 years). Tetra Tech predicts that downgradient arsenic concentrations would be up to 90 μg/l at 1000m downgradient and up to 20 μg/l at 5000m downgradient (Tetra Tech 1986, p.IV-114). Unlike in the Hennet modeling effort, Tetra Tech conducted site-specific adsorption experiments using tailings, soils, and groundwater to determine partition coefficients for arsenic, cadmium, copper, lead, and zinc at pH 3.0, 6.0, and 7.5 (Tetra Tech 1986, p. IV-76).

Finally, there is also a discrepancy in conclusions about the source of the contaminants in the alluvial groundwater when the Hennet and Tetra Tech reports are compared. Hennet ascribes the elevated arsenic concentrations at 26 feet below the water table to past disposal of sewage material (Hennet report, pg. 25). This far-fetched notion is contrasted with the clear statement from Tetra Tech (1986) that observed arsenic levels are the result of Smelter Hill wastes and tailings in the ponds (Tetra Tech 1986, p.II-145). Tetra Tech also states that the fact that arsenic is found farther downgradient than the other metals is consistent with its occurrence as a relatively more mobile, anionic species (Tetra Tech 1986, p. II-150).

10.0 ARCO'S USE OF CUMULATIVE FREQUENCY DIAGRAMS TO SHOW EXCEEDENCE OF RELEVANT WATER QUALITY STANDARDS

In Appendix C-1 of the Hennet report, analytical data from selected alluvial wells in the Upper Clark Fork basin were used to construct cumulative frequency diagrams for arsenic, cadmium, copper, fluorine, iron, manganese, lead, zinc, and sulfate. According to ARCO, these cumulative frequency diagrams can be used to assess the probability that concentrations in alluvial groundwater in the Upper Clark Fork basin will be below relevant water quality standards (Hennet 1995, p. C-1). The cumulative frequency diagrams show that, for the selected data, some of the concentrations exceed MCL and SMCL values. ARCO concludes that this demonstrates that certain chemical parameters, such as manganese and sulfate, are not appropriate for delineating injury because elevated concentrations of these parameters occur naturally (Hennet 1995, p. C-1).

There are incorrect assumptions and conclusions inherent in ARCO's argument on this issue. First, the data set is irrelevant, arbitrary, and diffuse. Some of the "selected" wells are in known groundwater injury areas. In addition, many of the wells are immediately adjacent to the Clark Fork River (Figure 7) in areas where streamside tailings line the river. Although the State has not claimed for groundwater injury under streamside tailings, most of these areas likely contain groundwater injured from leaching and downward transport of contaminants from the streamside tailings. In a given area, some wells were excluded from, and others were included in, the cumulative frequency diagrams. No reasoning was provided for the arbitrary nature of the well selection process.

Second, the NRDA regulations do not allow or imply that the use of cumulative frequency diagrams is acceptable practice for determining which parameters can be used to define or quantify injury, nor do the regulations suggest in any way that cumulative frequency diagrams can be used to assess groundwater quality. Groundwater injury is defined according to exceedence of relevant water quality standards (43 CFR §11.62(c)(1) and §11.62(c)(2)). And

Figure 7. Well Locations from Hennet 1995, Appendix C-1
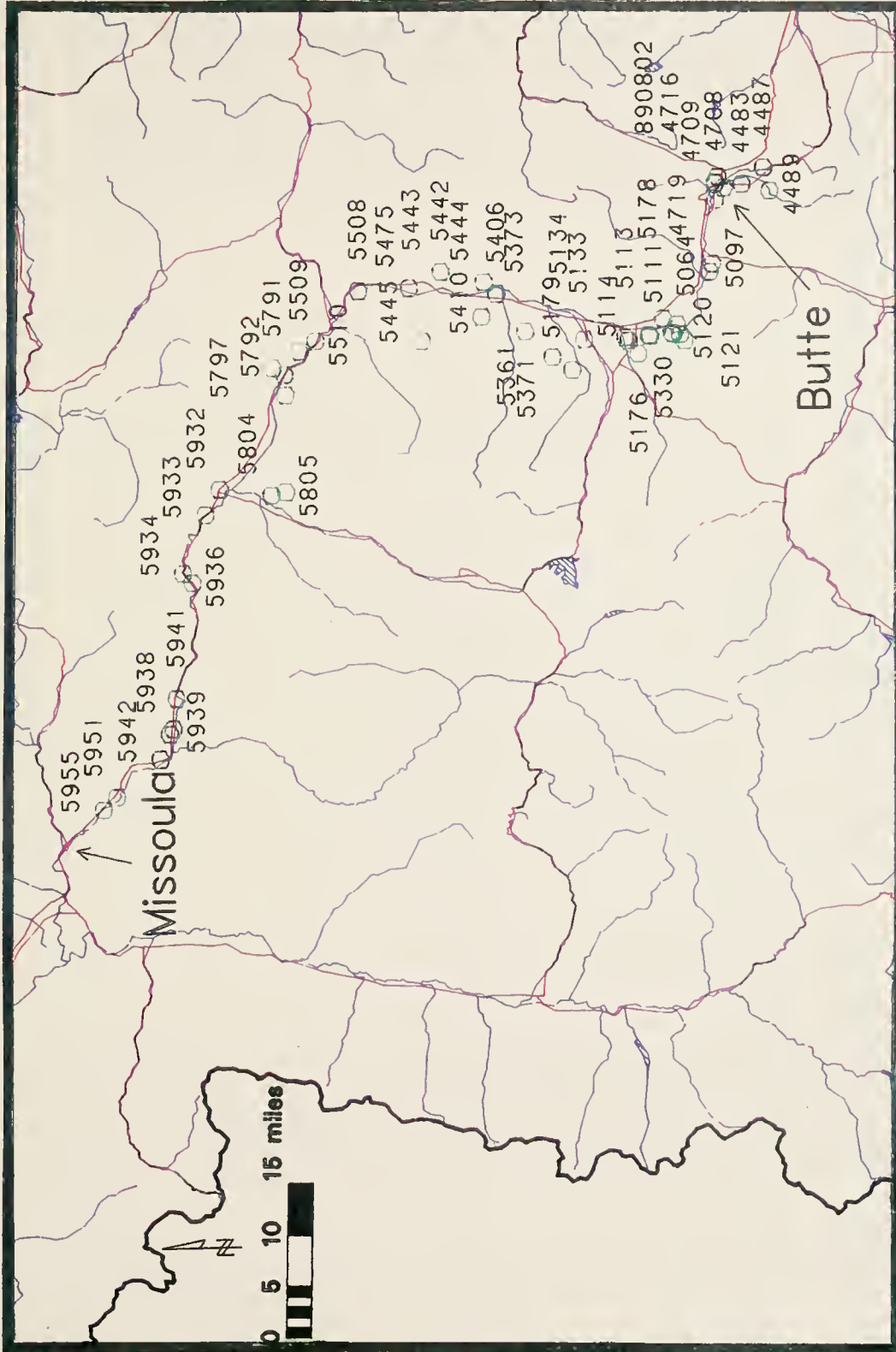
Source: Ted Duame, MBMG

groundwater injury is quantified relative to baseline conditions. In the State's groundwater injury reports, alluvial baseline water quality was established according to defined conditions, using wells that were as close as possible to areas where groundwater injury was being claimed for. Instead of selecting nearby wells that are not influenced by mining activity to determine baseline water quality, ARCO has arbitrarily selected wells all over the Clark Fork basin in areas where the State is not even claiming for groundwater injury. Therefore, ARCO's use of cumulative frequency diagrams to describe groundwater injury in any way is not supportable.

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REBUTTAL TO ARCO'S
GROUND WATER INJURY REPORTS
BY REMY J-C HENNET AND STEVEN P. LARSON

Ted Duaime   John Metesh

Ted Duaime Date _____   _John Metesh_ Date 10/5/95

HENNET Submittal

A. Dates of Operation of the Leach Pads at MR (Pg. 8 2a.)

Spindler (1977) reported that the leach pads were constructed at about the same time as the Weed Concentrator was constructed, the early 1960's; Personnel with the current operator of the leach pads, MR (formally known as Montana Resources, Inc.), confirm this estimate (personal communication between Ted Duaime [MBMG] and Steve Czehura and George Burns [MR], 9/5/95). No leach pads are seen in photographs of the area dated 1962. In fact, no access to the east side of Silver Bow Creek existed until the Yankee Doodle tailings pond was constructed. IECO (1981) reported that the construction of the tailings pond dam began in 1963; construction of the each pads was probably started about the same time.

The leach pads were operated continuously for about 20 years until all operations were suspended by ARCO. After a period of about a year, the leach pad operation was re-started by MR and has operated for less than 10 years; little or no expansion of the operation has occurred in the last 10 years.

Spindler, J.C., 1977, The Clean-Up of Silver Bow Creek, Mining Congress Journal, June, 1977, p58-62.

IECO, 1981, International Engineering Company, Inc., Geotechnical and Hydrologic Studies, Yankee Doodle Tailings Dam, Butte, Montana, prepared for Anaconda Company, Denver, Colorado, August, 1981, 97p. with 5 appendices.

B. Great Northern RR seep (Pg. 12 3d.):

The 1969 memorandum cited by Hennet is not available; however, the report submitted by Botz and Knudson (1970) describe natural stream and springs outside the

mining area as having low specific conductance, low dissolved minerals, and very low metal concentrations. There is no mention of poor quality water from natural sources.

Botz, M.K. and Knudson, G.L., 1970, Hydrogeology of the Berkeley Pit Area, Part I, The Alluvium, prepared for P.J.C. duToit, Chief Research Engineer, The Anaconda Company, April 7, 1970, 31p with appendices.

C. Baseline wells AW-1, AW-2, and AW-3 (Pg. 15 1c.):

The lithologic logs for AW-1, AW-2, and AW-3 are included in the Butte assessment report. The location of these wells were selected with the concurrence of ARCO's contractor (Canonie Environmental Services Corp.). In fact, three tributary drainages were recommended by Canonie as possible sites that would be within the mineralized area of the Butte Mining District, but would be outside the area disturbed by mining. It was agreed that the purpose of these wells was to determine background water quality in the alluvial aquifer. The selection of the sites was also the subject of an agreement between the State and ARCO in September 1992 and was strongly recommended by ARCO. Further investigation of the drainages resulted in one of the recommended sites being removed from consideration.

As evidenced by the mining activity nearby, all three wells are within what is considered the mineralized area (see for example SEG, 1973), but are not down gradient of any known, past mining activities. All three wells are in tributary drainages of the Butte basin. The lithologic description of each well indicates that the sediments were likely derived from mineralized parent rock. Iron-oxide staining and alteration is apparent in soil-samples from all three wells.

SEG, 1973, Guidebook for the Butte Field Meeting of Society of Economic Geologists, August 18-21, 1973, Butte, Montana, Presented by: Society of Economic Geologists, U.S. Geological Survey, and The Anaconda Company, Geological Department, 128p.

D. Historic Flows in Metro Storm Drain (Pg. 15 2a)

Spindler (1977) reported a flow of 13.6 cubic feet per second (cfs) at a station "0.5 miles below the Butte Operations on 7/14/76. Data collected by the Montana Bureau of Mines and Geology (Miller, 1974) from mid 1972 to early 1973 shows that discharge in Silver Bow Creek above Blacktail Creek ranged from 20 to 34 cfs. In both sampling programs, data collected at stations farther downstream indicated a gaining stream; there was little opportunity for surface water to discharge to ground water. Thus the contribution of surface-water contamination to ground-water contamination would be minimal.

Piper (1960) calculated a maximum spring runoff from the headwaters of Silver Bow Creek and from Woodville Canyon (also known as Elk Park Canyon) of 230 cfs and 255 cfs, respectively. The flow from these drainages (485 cfs) probably represent the majority of the flow in Silver Bow Creek at Texas Avenue and Continental Drive. Piper estimated a maximum, additional flow of 17.8 cfs, that originated from the mining operations. The mine discharge under these conditions amounts to only about 4% of the total flow. If the natural water from Silver Bow Creek and Woodville Canyon was of reasonably good quality, the metals loading by the mine discharge was probably insignificant.

Spindler, J.C., 1977, The Clean-Up of Silver Bow Creek, Mining Congress Journal, June, 1977, p58-62.

Miller M.R., Higgins, G.L., and Bond, E.W., 1974, Influence of Industrial and Private Wastes on Water Quality of the Upper Clark Fork River Drainage - A Reconnaissance Study, prepared by the Montana Bureau of Mines and Geology in cooperation with the Montana Department of Health and Environmental Sciences and the Anaconda Company, March, 1974, 54p.

Piper, R.D., 1960, Contamination of the Clark fork River from its Source in Silver Bow Creek, prepared for E.I., Renouard, The Anaconda Company, November 3, 1960, 15p.

E. Parrot Tailings and the upper Metro Storm Drain - physical characteristics (Pg 15 3a. and Pg. 17 5a.):

Ground-water divide, ground-water flow directions

Three sets of ground-water elevation data were evaluated: the Phase II Remedial Investigation (see Figure 3-49, CH_2M Hill and Chen-Northern, 1991), MBMG/ESE monitoring data for October, 1994 and MBMG/ESE monitoring data for April, 1995. The October, 1994 and April, 1995 data were selected to present conditions where ground water was at its highest and lowest levels with a complete set of data. All three sets of data indicate a ground-water divide near and parallel to Continental Drive. This position of the ground-water divide places most of the area known as the Parrot Tailings in the Silver Bow Creek drainage. In the best case, well GS-45, at the northeast end of the tailings area, is on or near the ground-water divide. When the dry wells north and east of the tailings area (AMC-10 and AMC-11) are considered, the divide is located farther toward the north and GS-45 is well within the Silver Bow Creek drainage. If the Parrot Park well and Well F, both of which are bedrock wells, are included, the divide still has an east-west orientation and is farther south, but, most of the area known as the Parrot Tailings is within the Silver Bow Creek drainage.

All of the nested wells in the Parrot Tailings area indicate a consistent, downward vertical gradient indicative of a ground-water recharge area, despite the lack of flow in the storm drain (period of record: January 1993 to July 1995). The average gradient for that period for each well is:

GS10S/D   -1.89

GS41S/D   -0.61

GS42S/D   -0.65

GS44S/D   -0.48

(negative indicates downward gradient)

Ground-water recharge, contaminant source areas

The area described as the upper Metro Storm Drain contains 190,000 cubic yards (c.y.) of tailings, 300,000 c.y. of slag, and 525,000 c.y. of waste rock for a total of 1.015

million cubic yards of material capable of leaching metals to ground water (CH_2M Hill and Chen-Northern, 1991). Only a small portion of the material over the tailings had been paved over prior to the 1990 investigation by CH_2M Hill and Chen-Northern. In aerial photographs taken on 9/22/47, much of the area is internally drained and appeared separate from Silver Bow Creek. By 7/30/77 the Butte Civic Center had been built and the area immediately surrounding it paved; the rest of the area between the civic center and Continental Drive remained open. By 1990, about one third of the total area between Harrison Avenue and Continental Drive was paved or covered by buildings. Two baseball fields were constructed on the north side. There is likely ground-water recharge to the tailings from the north and northeast and vertical recharge from the irrigated baseball fields and other open areas above the tailings. The downward vertical gradient also indicates significant recharge in the area.

In the investigation of Colorado Tailings, ARCO proposed that contaminated ground water in the Colorado Tailings area was "a manifestation of the regional ground-water flow system" (Dames and Moore, 1990). In other words, poor quality water from the Parrot Tailings moves downward and eventually moves upward into the Colorado Tailings area. The investigation included the completion of four bedrock wells in the Lower Area One Operable Unit; no deep (bedrock) contamination was found that area. Wells in the deeper alluvium were not installed.

CH_2M Hill and Chen-Northern, August, 29, 1991, <u>Draft Final</u> Silver Bow Creek CERCLA Phase II Remedial Investigation Data Summary, Area One Operable Unit, Volume I: Text, Document Number SBC-AREAI-DS-F-R2-082990,Prepared for the Montana Department of Health and Environmental Sciences, 7 Sections.

Dames and Moore, 1990, Colorado Tailings / Butte Reduction Works Accelerated Removals, Engineering Evaluation / Cost Analysis, <u>Draft Work Plan</u>, Prepared for ARCO Coal Company, April 25, 1990, 31p.

There is no evidence to suggest that ground-water contamination in the upper Silver Bow Creek area is attributable only to surface water discharge from the active mine area. The highest concentration of dissolved metals in ground-water are associated with the Parrot Smelter area or with tailings deposits along the creek, not with the creek. Concentration contours of dissolved metals tend to mimic present-day ground-water contours of an

influent stream rather than an effluent stream (for example, see Figure 3-22, CH$_2$M Hill and Chen-Northern, 1991). In general, if the stream is the source of contamination, the concentration of dissolved constituents in ground water increase downstream. If the source of contamination is within the aquifer, the concentration of dissolved constituents decrease downstream. The contaminant plume in the upper Silver Bow Creek area is consistent with a localized source area at or near the ground-water table; it is not consistent with a line-source such as a contaminated stream. "Hot spots" of contamination downstream are consistent with smaller local sources such as tailings deposits (for example, see Figure 3-25, CH$_2$M Hill and Chen-Northern, 1991).

LARSON Submittal

A. Porosity (Pg. 12 3.1.1.2):

Applicability of Snow (1964?)

Larson cites Snow (1964) as being a definitive paper on fracture porosity, yet provides no reference in the appropriate section of the report. At the Metesh deposition, at which Larson was present, ARCO presented an article by Snow published in 1968. It was in this article that the "over 5500 field tests" were presented. Simply put, the work presented by Snow (1968) has no application for the Butte bedrock aquifer.

In the abstract of the article, Snow states that "the result is likely to be conservative" when referring to estimating porosity. The method presented by Snow is for estimating the volume of grout used in the construction of dams; *all* of the field tests were conducted at dam sites. It is intuitive that dam sites are selected based on the low permeability of the underlying rock. Thus, the test sites were biased toward low permeability, low porosity rock. It is not surprising, therefore, that the values obtained from the tests indicate such low porosity. To suggest, as Larson does, that this should be applied to the Butte bedrock aquifer is misleading. In fact, Snow states that "The porosities given herein apply to most *hard* fractured rock formations, *but should not be applied to those parts that have been strongly weathered or disturbed by excavation, blasting or rock-sliding.*" [emphasis added]. Snow further states that "A *3-in to 4-ft* [fracture] *spacing* may be typical of the decompression zone around an underground cavern, *the fracture pattern due to blasting a mine drift, the weathered rock close to an outcrop*, or preserved at an unconformity, but is not typical of undisturbed rock masses. *This report does not include data from such highly disturbed rock, but rather, the uppermost 400 ft of relatively sound rock in the sloping abutments of dam sites.*" [text and emphasis added].

Snow, D.T., 1968, Rock Fracture Spacings, Openings, and Porosities, Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers, Vol. 94, No. SM1, January, 1968, p73-91.

Alternative Values/descriptions Presented in the Literature

Numerous articles can be found describing the extensive and pervasive nature of fractures in the bedrock in Butte. For example, Sales and Meyer (1948) describe the area as follows:

"Butte is an extensively fissured area. The country rock is quartz monzonite into which have been intruded a few narrow dikes of quartz porphyry.... The quartz porphyry was followed by extensive fracturing and mineralization resulting in what is known as the East-West system of veins. These veins are by far the most extensive and persistent of any in the district."

Sales, R.H. and Meyer, C., 1948, Wall-Rock Alteration at Butte, Montana, AIME Transactions, New York meeting, February, 1948, p9-33.

Other descriptions of the extensive and pervasive nature of fractures in the Butte Mining district include the USGS (1978).

U.S. Geological Survey, 1978, Geologic Atlas of the United States, Butte Special Folio, List of Sheets, Folio 38, 1978.

While "fissures and fractures" are often partially in-filled by mineralization, the extensive and persistent nature of the fractures, even at depth, indicates that there are open fractures available for ground-water flow. In fact, Henley (1978) describes ground water as a critical component of porphyry copper emplacement.

Henley, R.W. and McNabb, 1978, Magmatic Vapor Plumes and Ground-Water Interaction in Porphyry Copper Emplacement, Economic Geology, Vol 73, No. 1, Jan-Feb 1978, 20p.

"The abundance of fractures commonly observed in pluton environments suggests that many of these rocks are host to extensive fluid circulation." (Norton ,1978)

Norton, D., 1978, Sourcelines, Sourceregions, and Pathlines for Fluids in Hydrothermal Systems Related to Cooling Systems, Economic Geology, Vol. 73, No.1, 1978, pp 21-28.

In a model developed to describe the relationship between intrusives and copper-porphyry ore deposits (Cathles, 1977) uses a "total formation" porosity of 2 to 4 percent.

Cathles, L.M., 1977, An Analysis of the Cooling of Intrusives by Ground-Water Convection which Includes Boiling, Economic Geology, Vol. 72, 1977, p804-826.

Sales (1913) describes a wide range of ground-water flow at all depths of the Butte mines. Further, he describes the occurrence of "sooty chalcocite" which is deposited by ground water at depths 200 to 1200 feet below the " zone of oxidation".

Sales, R.H., 1913, Ore Deposits at Butte, Montana, AIME Transactions, Butte, Montana meeting August, 1913, p3-109.

Daly (1923) describes the concern for fractured rock in mining operations. Sloughing and caving were common in areas where the rock had been altered by hydrothermal activity and indicates the fractured nature of the rock and its ability to transmit water.

The pumping rates described by Daly (1923) also give evidence to the amount of water encountered in the Butte District. At that time, there were 39 pumps in operation and although no pumping rate was reported, the pumping capacity of these pumps was about 19000 gallons per minute (28 mgd).

Daly, W.B., Gillie, J., Bruce, J.L., Berrien, C.L., and Braly, N.B., 1923, Mining Methods in the Butte District, AIME Transactions, New York meeting, February, 1923, p235-287.

Fessenden (1915) describes samples collected from "a stream of water coming from a quartz pyrite vein" at the 2600-foot level of the "Butte mine" and from the 3400-foot level of the same mine. While no discharge rate was reported, there was no special effort to find flowing water at these depths. Both waters were interpreted as "vadose" water or water from the surface.

Fessenden, M.T., 1915, Analysis of Deep Mine Waters, Unpublished Thesis, Tufts College, Department of Chemistry, June 10, 1915, 15p.

The 1% porosity has been used by other workers familiar with the bedrock in the Butte area. In the Remedial Investigation Report (Canonie, 1994) and in the Record of Decision, (Titan ,1994) a value of 1% is used in estimating the volume of ground water affected by mining.

Canonie, 1994, Draft Butte Mine Flooding Operable Unit Remedial Investigation / Feasibility Study, Prepared by Canonie Environmental Services, prepared for ARCO, January, 1994, 3 volumes.

Titan, 1994, *in* Record of Decision, Butte Mine Flooding Operable Unit, Silver Bow Creek / Butte Area NPL Site, Butte, Montana, September 29, 1994, Attachment 1, Volume Calculations by Titan Environmental, 9/8/94.

B. Water-supply from the Bedrock Aquifer (Pg. 15 3.1.1.2):

There are many examples of the actual and potential productive nature of the bedrock aquifer in the Butte area. Records of the drainage and pumping rates of the mines and recent development of the bedrock aquifer outside the influence of mining indicate a viable productive aquifer.

Several reports published throughout the history of large-scale mining in Butte have reported discharge rates

1932   3500 gpm (Perry, 1932) [average depth of mines: 2000 to 3000 feet]
1960   4957 gpm (Goddard, 1960) [flow measured at surface weir, October, 1960]
1961   5036 gpm (Fogarty, 1961) [total discharge for pumping charges]
1981   5200 gpm (CH_2M Hill, 1981)

The pumping rate increased about 1700 gpm or 49% over about 49 years.

Perry, E.S., 1932, The Butte Mining District, Montana, International Geological Congress, XVI Session, United States, 1933, Guidebook 23, Excursion C-2, 25p with plates.

Goddard, C.C., 1960, Copper Water in the Butte Mines and Suggestions as to Distribution of Copper Derived Therefrom the Various Mine Units, Unpublished (?) report to Anaconda Company, November 23, 1960, 7p.

Fogarty, W.J., 1961, Distribution of Copper Credits and Pumping Charges for Water - Butte District, January, 1961, Unpublished fly sheet attached to letter from W.J. Fogarty, Assistant Secretary and Assistant Treasurer, Anaconda Company to E.P. Shea, Chief Geologist - Montana Operations, The Anaconda Company, February 22, 1961.

CH$_2$M Hill, 1981, Quarterly Report on the Phase II Water Management Study for the Butte Operations, May 5, 1981, prepared for Anaconda Company, 71p., 3 appendices.

Goddard (1953) reported drainage rates for several areas of the Butte mines:

Anselmo 1700 drifts:	70 gpm
Black Rock - Badger 2400 level:	20 gpm
Belmont Moonlight system	
400 station:	25 gpm
1500 station:	25 gpm
Belmont Colorado system	
1700 station:	25 gpm
1900 station:	25 gpm

The Goddard report also describes discharge from drain holes throughout the mines but does not generally specify depth. Drainage in the Mountain Consolidated (a.k.a. Mountain Con) is described in detail:

South Side:

3900 level:	30 gpm
4000 level:	40 gpm
4100 level:	75 gpm
4200 level:	105 gpm

North Side:

3900 level:	15 gpm
4000 level:	45 gpm
4200 level:	60 gpm

The total amount collected (both north and south sides) was reported as 380 gpm. The production of water from depths of 4200 feet is significant.

Goddard, C.C., 1953, Unpublished Memorandum entitled Water Drainage in the Butte Mines to E.I. Renouard, November 23, 1953, 26p.

Many of the wells in the sparsely populated area south of Butte are completed in the bedrock aquifer. A query of the MBMG Ground Water Information Center database shows 174 wells with an average depth of 170.5 feet, an average yield of 18.8 gallons per minute (Appendix A). The total reported yield for these wells is about 3190 gallons per minute. There have been few, if any, reports of water shortages despite the intense usage.

C. An Accurate Drainage Area Calculation (Pg. 19 3.1.3):

Larson suggests that the drainage area of the original Silver Bow Creek is "about one-tenth the size of the Blacktail Creek watershed..." (one tenth of 90 square miles). The drainage area of the upper Silver Bow Creek, in the absence of mining and mining related structures is, in fact, about 23 square miles (U.S. EPA, 1994, Canonie, 1994). In work related to the Yankee Doodle tailings impoundment, IECO (1981) reported the drainage area of the upper Silver Bow Creek and Yankee Doodle Creek as 13.8 square miles; this would exclude the drainage area below the tailings dam. The area below the dam can be estimated by taking the difference in drainage area calculated by the USGS for Blacktail Creek and the present-day Silver Bow Creek which gives 7.6 square miles. The total drainage based on the IECO value for the drainage area above the dam and the area calculated by the USGS below the dam is 21.4 square miles.

U.S. EPA, 1994, Record of Decision, Butte Mine Flooding Operable Unit, Silver Bow Creek / Butte Area NPL Site, Butte, Montana, September 29, 1994, 3 Volumes.

Canonie, 1994, Butte Mine Flooding Operable Unit Remedial Investigation / Feasibility Study, Prepared by Canonie Environmental Services, prepared for ARCO, March, 1994, 3 volumes.

IECO, 1981, International Engineering Company, Inc., Geotechnical and Hydrologic Studies, Yankee Doodle Tailings Dam, Butte, Montana, prepared for Anaconda Company, Denver, Colorado, August, 1981, 97p.. with 5 appendices.

D. Butte Water System Leakage Rates and Locations

James M. Montgomery reported a total system leakage of 2.4 million gallons per day (mgd) for the Butte water system. This volume was apparently based on Butte Water Company data; the distribution of this leakage was not reported. However, since the entire water-supply system was investigated, it is intuitive that the 2.4 mgd (1666 gallons per minute) is distributed throughout the Butte area and the proportion of the that volume going into the mines would be insignificant. In fact, few of the areas recommended by Montgomery for repair or replacement are on the Butte hill.

James M. Montgomery, 1988, Butte Water System Master Plan, presented to: Butte-Silver Bow Government and Butte Water Company, January, 1988, 146p, 4 appendices.

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Daly, W.B., Gillie, J., Bruce, J.L., Berrien, C.L., and Braly, N.B., 1923, Mining Methods in the Butte District, AIME Transactions, New York meeting, February, 1923, p235-287.

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Miller M.R., Higgins, G.L., and Bond, E.W., 1974, Influence of Industrial and Private Wastes on Water Quality of the Upper Clark Fork River Drainage - A Reconnaissance Study, prepared by the Montana Bureau of Mines and Geology in cooperation with the Montana Department of Health and Environmental Sciences and the Anaconda Company, March, 1974, 54p.

Cathles, L.M., 1977, An Analysis of the Cooling of Intrusives by Ground-Water Convection which Includes Boiling, Economic Geology, Vol. 72, 1977, p804-826.

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James M. Montgomery, 1988, Butte Water System Master Plan, presented to: Butte-Silver Bow Government and Butte Water Company, January, 1988, 146p, 4 appendices.

Dames and Moore, 1990, Colorado Tailings / Butte Reduction Works Accelerated Removals, Engineering Evaluation / Cost Analysis, Draft Work Plan, Prepared for ARCO Coal Company, April 25, 1990, 31p.

CH$_2$M Hill and Chen-Northern, August, 29, 1991, Draft Final Silver Bow Creek CERCLA Phase II Remedial Investigation Data Summary, Area One Operable Unit, Volume I: Text, Document Number SBC-AREAI-DS-F-R2-082990, Prepared for the Montana Department of Health and Environmental Sciences, 7 Sections.

Canonie, 1994, Draft Butte Mine Flooding Operable Unit Remedial Investigation / Feasibility Study, Prepared by Canonie Environmental Services, prepared for ARCO, January, 1994, 3 volumes.

Canonie, 1994, Butte Mine Flooding Operable Unit Remedial Investigation / Feasibility Study, Prepared by Canonie Environmental Services, prepared for ARCO, March, 1994, 3 volumes.

Titan, 1994, *in* Record of Decision, Butte Mine Flooding Operable Unit, Silver Bow Creek / Butte Area NPL Site, Butte, Montana, September 29, 1994, Attachment 1, Volume Calculations by Titan Environmental, 9/8/94.

U.S. EPA, 1994, Record of Decision, Butte Mine Flooding Operable Unit, Silver Bow Creek / Butte Area NPL Site, Butte, Montana, September 29, 1994, 3 Volumes.

APPEDIX A
LISTING OF WELLS COMPLETED IN THE BEDROCK AQUIFER SOUTH BUTTE AREA

LIST WELLS AQUIFER AVERAGE TD AVERAGE YIELD LOCAT BY LOCAT 13:47:04   09-12-95
PAGE   1

WELL NO.	AQUIFER...	TOTAL DEPTH FEET....	YIELD GPM.....	LOCATION............	
M:48727	211BDBT	220.0	40.0	01N 07W 04 CBBA	
M:121972	211BDBT	80.0	11.0	01N 07W 05 AAA	01
M:48731	211BDBT	32.0	4.0	01N 07W 05 AAC	
M:48732	211BDBT	38.0	3.0	01N 07W 05 ADCA	
M:48733	211BDBT	55.0	15.0	01N 07W 05 ADCA	
M:48734	211BDBT	65.0	4.0	01N 07W 05 ADCD	
M:48736	211BDBT	55.0	8.0	01N 07W 05 DA	
M:48737	211BDBT	54.0	30.0	01N 07W 05 DAAB	
M:48738	211BDBT	75.0	12.0	01N 07W 05 DAAD	
M:48739	211BDBT	79.0	6.0	01N 07W 05 DABC	
M:128637	211BDBT	225.0	10.0	01N 07W 05 DBB	01
M:48740	211BDBT	62.0	6.0	01N 07W 05 DCCB	
M:120289	211BDBT	90.0	30.0	01N 07W 05 DD	01
M:136940	211BDBT	180.0	9.0	01N 07W 06 ACA	01
M:48741	211BDBT	90.0	10.0	01N 07W 08 A	
M:138336	211BDBT	63.0	20.0	01N 07W 08 ADA	01
M:48742	211BDBT	280.0	12.0	01N 07W 08 ADCC	
M:107100	211BDBT	120.0	15.0	01N 07W 08 ADD	01
M:48743	211BDBT	105.0	20.0	01N 07W 08 D	
M:145950	211BDBT	125.0	20.0	01N 07W 08 DAA	01
M:48745	211BDBT	240.0	15.0	01N 07W 09	
M:48744	211BDBT	320.0	3.0	01N 07W 09	
M:48746	211BDBT	55.0	7.0	01N 07W 09	
M:131138	211BDBT	160.0	10.0	01N 07W 09	01
M:48747	211BDBT	130.0	20.0	01N 07W 09 B	
M:48748	211BDBT	115.0	20.0	01N 07W 09 B	
M:48749	211BDBT	178.0	10.0	01N 07W 09 BAC	
M:48750	211BDBT	90.0	15.0	01N 07W 09 BB	
M:48751	211BDBT	75.0	20.0	01N 07W 09 BC	
M:133600	211BDBT	285.0	8.0	01N 07W 09 BC	01
M:48752	211BDBT	60.0	5.0	01N 07W 09 BCCB	
M:48753	211BDBT	135.0	10.0	01N 07W 09 BD	
M:48755	211BDBT	120.0	15.0	01N 07W 09 BDDB	
M:134920	211BDBT	210.0	18.0	01N 07W 09 CAC	01
M:48756	211BDBT	220.0	10.0	01N 07W 09 CBD	
M:48757	211BDBT	300.0	8.0	01N 07W 09 DCCD	
M:133602	211BDBT	240.0	8.0	01N 07W 12 DD	01
M:48758	211BDBT	90.0	7.0	01N 07W 13 A	
M:48759	211BDBT	84.0	8.0	01N 07W 13 AA	
M:48760	211BDBT	100.0	8.0	01N 07W 13 AAA	
M:48761	211BDBT	230.0	4.0	01N 07W 13 AAC	
M:48762	211BDBT	320.0	13.0	01N 07W 13 ABDC	
M:120992	211BDBT	178.0	13.0	01N 07W 13 AC	01
M:120991	211BDBT	128.0	16.0	01N 07W 13 AC	01
M:120990	211BDBT	275.0	7.0	01N 07W 13 AC	01
M:48763	211BDBT	180.0	8.0	01N 07W 16	
M:48764	211BDBT	230.0	12.0	01N 07W 16 AC	
M:120290	211BDBT	127.0	20.0	01N 07W 16 AC	01
M:48765	211BDBT	127.0	25.0	01N 07W 16 ACBA	

WELL NO.	AQUIFER...	TOTAL DEPTH FEET....	YIELD GPM.....	LOCATION.............	
M:48766	211BDBT	160.0	12.0	01N 07W 16 ACCB	
M:48767	211BDBT	167.0	3.0	01N 07W 17 A	
M:143496	211BDBT	70.0	15.0	01N 07W 17 AA	01
M:48769	211BDBT	65.0	7.0	01N 07W 17 B	
M:48768	211BDBT	100.0	2.0	01N 07W 17 B	
M:48770	211BDBT	65.0	4.0	01N 07W 17 B	
M:127987	211BDBT	200.0	15.0	02N 07W 03 D	01
M:49244	211BDBT	62.0	7.0	02N 07W 03 DB	
M:49246	211BDBT	232.0	15.0	02N 07W 04 AA	
M:49247	211BDBT	201.0	20.0	02N 07W 04 AA	
M:49248	211BDBT	107.0	15.0	02N 07W 04 AACA	
M:49249	211BDBT	126.0	15.0	02N 07W 04 AACD	
M:49250	211BDBT	135.0	30.0	02N 07W 04 AADD	
M:49251	211BDBT	120.0	14.0	02N 07W 04 ABAC	
M:49252	211BDBT	110.0	14.0	02N 07W 04 ABBD	
M:49253	211BDBT	95.0	30.0	02N 07W 04 ABD	01
M:49254	211BDBT	125.0	25.0	02N 07W 04 ABD	01
M:49362	211BDBT	60.0	10.0	02N 07W 13 AC	
M:133612	211BDBT	80.0	20.0	02N 07W 13 DA	01
M:126678	211BDBT	80.0	30.0	02N 07W 14 BC	01
M:49489	211BDBT	150.0	20.0	02N 07W 20 D	
M:127060	211BDBT	60.0	25.0	02N 07W 20 DA	01
M:49490	211BDBT	30.0	5.0	02N 07W 20 DBAB	
M:49491	211BDBT	30.0	5.0	02N 07W 20 DBAB	
M:49492	211BDBT	30.0	5.0	02N 07W 20 DBAB	
M:127864	211BDBT	205.0	15.0	02N 07W 21 CC	01
M:141249	211BDBT	180.0	6.0	02N 07W 21 CCDDA	01
M:147110	211BDBT	64.0	25.0	02N 07W 21 CD	01
M:49531	211BDBT	97.0		02N 07W 21 DDA	
M:49532	211BDBT	53.0	10.0	02N 07W 21 DDAC	
M:49533	211BDBT	50.0	6.0	02N 07W 21 DDAD	
M:49564	211BDBT	76.0	10.0	02N 07W 22 DACD	01
M:49565	211BDBT	45.0	10.0	02N 07W 22 DB	
M:49566	211BDBT	35.0	8.0	02N 07W 22 DBAD	
M:49567	211BDBT	80.0	500.0	02N 07W 22 DBBC	
M:149205	211BDBT	240.0	10.0	02N 07W 22 DC	01
M:145960	211BDBT	100.0	10.0	02N 07W 22 DDA	01
M:49568	211BDBT	100.0		02N 07W 22 DDA	01
M:49569	211BDBT	140.0	100.0	02N 07W 22 DDAB	
M:49570	211BDBT	340.0	6.0	02N 07W 23 ACD	
M:120301	211BDBT	325.0	7.5	02N 07W 23 BD	01
M:149206	211BDBT	220.0	30.0	02N 07W 23 CCC	01
M:4491	211BDBT	140.0	40.0	02N 07W 23 DBAB	01
M:49575	211BDBT	170.0	20.0	02N 07W 23 DBBA	
M:150589	211BDBT	210.0	12.0	02N 07W 25 BBC	01
M:49577	211BDBT	280.0	9.0	02N 07W 27	
M:127649	211BDBT	360.0	4.0	02N 07W 27 B	01
M:49578	211BDBT	303.0	8.0	02N 07W 27 BBA	
M:123333	211BDBT	240.0	10.0	02N 07W 27 CB	01
M:143509	211BDBT	281.0	15.0	02N 07W 28 BAA	01
M:130132	211BDBT	138.0	12.0	02N 07W 29	01
M:124086	211BDBT	96.0	15.0	02N 07W 29 BB	01
M:124087	211BDBT	87.0	20.0	02N 07W 29 BB	01
M:49580	211BDBT	34.0	5.0	02N 07W 31 BAAD	

WELL NO.	AQUIFER...	TOTAL DEPTH FEET....	YIELD GPM.....	LOCATION............
M:127985	211BDBT	200.0	9.0	02N 07W 31 BC 01
M:49581	211BDBT	140.0	5.0	02N 07W 32 ADDC
M:49582	211BDBT	60.0	5.0	02N 07W 32 B
M:49584	211BDBT	47.0		02N 07W 32 DBBC
M:49585	211BDBT	40.0	20.0	02N 07W 32 DCAA
M:147196	211BDBT	104.0	20.0	02N 07W 34 CD 01
M:49586	211BDBT	120.0	8.0	02N 08W 01 CBB
M:33694	211BDBT	152.0	12.0	02N 08W 02 01
M:49587	211BDBT	300.0	10.0	02N 08W 02 AACA
M:49588	211BDBT	127.0	12.0	02N 08W 02 CC
M:49589	211BDBT	250.0	1.0	02N 08W 02 CC
M:49590	211BDBT	190.0	20.0	02N 08W 02 D
M:49592	211BDBT	123.0	10.0	02N 08W 02 D
M:49591	211BDBT	220.0	5.0	02N 08W 02 D 01
M:49593	211BDBT	110.0	20.0	02N 08W 02 DD
M:49594	211BDBT	81.0	13.0	02N 08W 02 DDBC
M:49595	211BDBT	208.0	20.0	02N 08W 03 CC
M:49596	211BDBT	158.0	10.0	02N 08W 03 CC
M:49597	211BDBT	100.0	20.0	02N 08W 03 DCD
M:49598	211BDBT	180.0	30.0	02N 08W 04 BDDB
M:49599	211BDBT	360.0	64.0	02N 08W 04 CABC
M:49600	211BDBT	300.0	69.0	02N 08W 04 DBAA
M:49602	211BDBT	125.0	12.0	02N 08W 10 AA
M:49603	211BDBT	130.0	15.0	02N 08W 10 B
M:120995	211BDBT	182.0	15.0	02N 08W 11 AD 01
M:34689	211BDBT	175.0	15.0	02N 08W 12 01
M:49606	211BDBT	180.0	50.0	02N 08W 12 D
M:49605	211BDBT	140.0	8.0	02N 08W 12 D
M:120302	211BDBT	200.0	12.0	02N 08W 12 DC 01
M:49607	211BDBT	180.0	35.0	02N 08W 14 AA
M:49608	211BDBT	300.0	8.0	02N 08W 14 AB
M:49610	211BDBT	150.0	20.0	02N 08W 14 ABB
M:49609	211BDBT	240.0		02N 08W 14 ABB
M:120303	211BDBT	120.0	22.0	02N 08W 14 AC 01
M:130134	211BDBT	140.0	25.0	02N 08W 14 AC 01
M:138355	211BDBT	120.0	20.0	02N 08W 14 ADD 01
M:49611	211BDBT	120.0	40.0	02N 08W 14 BD
M:49612	211BDBT	40.0	5.0	02N 08W 14 CCAB
M:49613	211BDBT	125.0	30.0	02N 08W 15 DABC
M:49615	211BDBT	125.0	12.0	02N 08W 22 BD
M:4492	211BDBT	460.0	12.0	02N 08W 22 CBCA 01
M:49617	211BDBT	275.0	40.0	02N 08W 22 CC 01
M:49618	211BDBT	320.0	5.0	02N 08W 22 CDCB
M:49619	211BDBT	240.0	9.0	02N 08W 22 CDCD 01
M:49620	211BDBT	190.0	20.0	02N 08W 22 DCC 01
M:49621	211BDBT	320.0	8.0	02N 08W 22 DCCA 01
M:49622	211BDBT	165.0	20.0	02N 08W 22 DDAD 01
M:49623	211BDBT	80.0	22.0	02N 08W 22 DDAD 01
M:49624	211BDBT	240.0	30.0	02N 08W 22 DDBB
M:49625	211BDBT	190.0	35.0	02N 08W 22 DDBD
M:49633	211BDBT	420.0	9.0	02N 08W 23 C 01
M:49634	211BDBT	300.0	15.0	02N 08W 23 CA
M:144717	211BDBT	334.0	18.0	02N 08W 23 CAC 01
M:133645	211BDBT	250.0	25.0	02N 08W 23 CB 01

WELL NO.	AQUIFER...	TOTAL DEPTH FEET....	YIELD GPM.....	LOCATION............	
M:49635	211BDBT	365.0	60.0	02N 08W 23 CBBD	
M:49636	211BDBT	350.0	5.0	02N 08W 23 CDA	
M:128061	211BDBT	360.0	11.0	02N 08W 23 CDD	01
M:49637	211BDBT	345.0	7.0	02N 08W 23 DCD	
M:49638	211BDBT	260.0	6.0	02N 08W 23 DCD	
M:49639	211BDBT	200.0	25.0	02N 08W 25 ABB	
M:141258	211BDBT	400.0	6.0	02N 08W 25 ACB	01
M:120307	211BDBT	200.0	15.0	02N 08W 25 BB	01
M:49644	211BDBT	320.0	12.0	02N 08W 25 BBB	
M:49645	211BDBT	125.0	25.0	02N 08W 25 BC	
M:120306	211BDBT	200.0	30.0	02N 08W 25 CA	01
M:120308	211BDBT	300.0	5.0	02N 08W 25 CA	01
M:120309	211BDBT	280.0	15.0	02N 08W 25 CA	01
M:49650	211BDBT	265.0	12.0	02N 08W 26 AAA	01
M:125816	211BDBT	460.0	20.0	02N 08W 26 BB	01
M:121381	211BDBT .	425.0	7.0	02N 08W 26 BB	01
M:49659	211BDBT	225.0	20.0	02N 08W 36 A	

174 records listed.

REBUTTAL

OF THE EXPERT REPORTS OF

REMY J. C. HENNET, Ph.D. and STEVEN P. LARSON
Prepared for Atlantic Richfield Company

State of Montana v. Atlantic Richfield Company

Prepared by

WILLIAM W. WOESSNER, Ph.D.

(signature)
Signature

10/5/95
Date

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INTRODUCTION

I have reviewed the groundwater related portions of the expert reports submitted by Remy Hennet and Steven Larson in the State of Montana vs Atlantic Richfield Company, a natural resource damage claim. I have chosen to rebut portions of their analyses based on my familiarity with the sites and my expertise. My comments focus on issues related to the injury to groundwater resources.

REBUTTAL OF HENNET

Hennet states on page 19 that the presence of high iron and manganese concentrations in the groundwater at the Rocker site does not, in itself, indicate that an impact related to the wood treatment operation has occurred.

The source of the "arsenic compound" used to treat wood at the Rocker site was the arsenic plant at the Anaconda Smelter Site. This plant was used to remove some of the arsenic from the smelter emissions (Newell, 1995). Arsenic compounds derived from the flue dust would contain not only arsenic but also extremely high concentrations of hazardous materials and related metals (Woessner, 1995). Much of the groundwater contamination found at the Rocker site is most likely related to the processes used to treat wood on site. Groundwater arsenic, cadmium, copper, zinc, manganese and iron plumes all underlie the plant facilities south of Silver Bow Creek. In addition to the introduction of arsenic and other hazardous compounds from the facility source to the underlying groundwater, the site also contains streamside tailings as do the adjacent floodplains to north, east and west of the plant site. Figure 1 shows the mapped location of stream side tailings (Titan, 1995). Injured groundwater appears to be most closely associated with the Rocker facility. The presence of manganese, iron and sulfate north of the creek is most-likely do to either the transport of these compounds from the site area or the impact of streamside tailings on the underlying groundwater. Complex transport mechanisms and the release of metals from stream side tailings has been recognized by Benner (1994) and Smart (1995) at the Miles Cross Silver Bow Creek floodplain research site located west of Rocker.

Benner, S.G., 1994, Geochemical processes in a transition zone between surface water and acidic, metal-rich groundwater, Master of Science Thesis, Department of Geology, University of Montana, Missoula, unpublished, 71 pp.

Smart, E. W., 1995, Surface water and groundwater interaction i a shallow unconfined alluvial aquifer and small mountain streams, Silver Bow Creek, Montana, Master of Science Thesis, Department of Geology, University of Montana, Missoula, unpublished, 170 pp.

Newell, A.S., 1995, A brief historical overview of Anaconda Copper
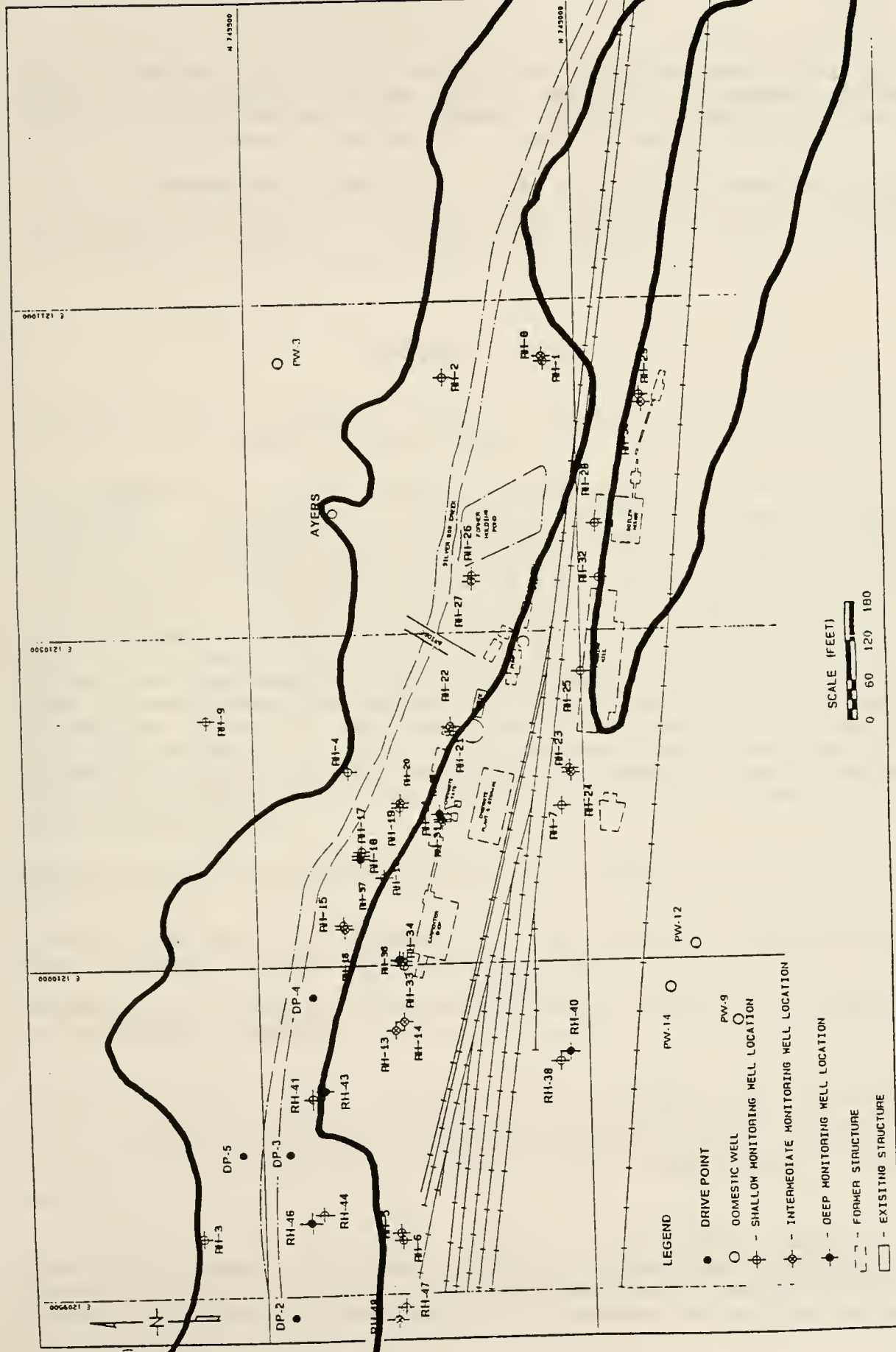
Figure 1: Location of mapped streamside tailings in the vicinity of the Rocker Site (Titan, 1995).

Mining Company's principal mining and smelting facilities along Silver Bow and Warm Springs Creeks, Montana. Prepared for MT. Depart. of Justice, Nat. Res. Damage Litigation Program, prepared by Historical Research Associates, Inc., Missoula, 64 pp.

Titan Environmental Corporation, 1995, Silver Bow Creek/Butte area NPL site streamside tailings operable unit RI/FS, Draft remedial investigation report. Prepared for ARCO, Prepared by Titan Environmental Corporation, Bozeman, MT. Vol 1.

REBUTTAL LARSON

Larson states on page nine that 0.20 should be uniformly used as the porosity of saturated sediments.

The argument to use a single porosity value of 20% is poorly supported. An average or range of values that appropriately represents the porosity of the geologic materials being evaluated should be selected instead of an arbitrary value. Values for sand and gravel are reported to range from 20 to 50 percent by Fetter (1994)(Table 1). Individual values reported for sand range from 25 to 53 percent (Freeze and Cherry, 1979; Domenico and Schwartz, 1990). The same authors report silt having a porosity of 34 to 61 percent and clay deposits porosities ranging from 34 to 70 percent. Much of the unconsolidated material making up the aquifers along Silver Bow Creek, in the Deerlodge Valley and at Milltown are combinations of clay, silt, sand, and sand and gravel deposits. Values that appropriately represent the deposits should be used when calculating the total volume of water contaminated by hazardous materials.

Fetter, C.W., 1994, Applied hydrogeology. Macmillan, New York, New York, 691 pp.

Freeze, R.A. and J.A. Cherry, 1979, Groundwater. Prentice-Hall, Inc, Englewood Cliffs, New Jersey, 604 pp.

Domenico, P.A. and F.W. Schwartz, 1990, Physical and chemical hydrogeology. John Wiley & Sons, 824 pp.

Larson on page 30 and 31 presents data to support his hypotheses that the vertical hydraulic conductivity beneath the lower portion of the Opportunity ponds is low and that the vertical extent of migration of contaminants is limited to the "upper most part of the aquifer".

The concentration of sulfate found in groundwater beneath the Opportunity ponds was presented by ARCO's consultants (Figure 34, Woessner, 1995). This plot shows that hazardous materials released from the tailings has resulted in the movement of sulfate to over

TABLE 4.3   Porosity ranges for sediments

Well-sorted sand or gravel ·	25–50%
Sand and gravel, mixed	20–35%
Glacial till	10–20%
Silt	35–50%
Clay	33–60%

Based on Meinzer (1923a); Davis (1969); Cohen (1965); and MacCary and Lambert (1962).

(Fetter, 1994)

Table 2.1
Range in values of porosity (in part from Davis, 1969, and Johnson and Morris, 1962)

Material	Porosity (%)
SEDIMENTARY	
Gravel, coarse	24–36
Gravel, fine	25–38
Sand, coarse	31–46
Sand, fine	26–53
Silt	34–61
Clay	34–60
SEDIMENTARY ROCKS	
Sandstone	5–30
Siltstone	21–41
Limestone, dolomite	0–20
Karst limestone	5–50
Shale	0–10
CRYSTALLINE ROCKS	
Fractured crystalline rocks	0–10
Dense crystalline rocks	0–5
Basalt	3–35
Weathered granite	34–57
Weathered gabbro	42–45

(Domenico and Schwartz, 1990)

Table 2.4   Range of Values of Porosity

	$n(\%)$
Unconsolidated deposits	
Gravel	25–40
Sand	25–50
Silt	35–50
Clay	40–70
Rocks	
Fractured basalt	5–50
Karst limestone	5–50
Sandstone	5–30
Limestone, dolomite	0–20
Shale	0–10
Fractured crystalline rock	0–10
Dense crystalline rock	0–5

(Freeze and Cherry, 1979)

Figure 34: Sulfate concentrations beneath and down-gradient of Opportunity Ponds (ESE, 1994).

150 feet below the land surface. At this depth, concentrations exceed SMCL by over five times. Sulfur isotope data presented by Hennet and discussed by Maest in her rebuttal report, indicate a non-geothermal source of this sulfate. Concentration gradients clearly indicate the sulfate is originating from the tailings ponds. This evidence contradicts the hypotheses that the field scale vertical hydraulic conductivities of sediments underlying Opportunity Ponds is sufficiently small to prevent migration of contaminants into deeper portions of the aquifer.

On page 31, Larson states groundwater flow conditions presented in my Anaconda groundwater report over estimate the discharge of groundwater beneath Opportunity ponds.

Increased stream flow in the Mill-Willow By-Pass is implied to represent the major portion of the discharge of groundwater from the tailings ponds area. Certainly Mill-Willow By-Pass would appear to receive some of the shallow groundwater discharge from the Opportunity ponds area. However, no hydrogeologic data supports the fact that the entire groundwater system flowing beneath the ponds is discharging to the by-pass. Hydraulic gradients east of Opportunity ponds are northeastward and downward. Vertical gradient data in the area immediately west of the by pass has not been collected nor has the presence of a hydrologic divide at depth been rejected. The calculation of groundwater discharge rates from the ponds area are based on standard hydrogeologic methods and are reasonable based on the available data.

Also on page 32, Larson questions the mapping of hazardous materials in groundwater south of Anaconda and Opportunity Ponds.

Hazardous materials are present on the land surface south of the two principal tailings ponds at Anaconda. The source of these contaminants is directly related to tailings deposited by Silver Bow Creek and related irrigations ditches, the Yellow Ditch that supplied water to the large tailings pond area (Newell, 1995), air fall of particulate from the smelter operations, and failure of tailings pond berms and ditches that distributed tailing beyond the boundaries of these structures (Newell, 1995). Figure 2 presents a representation of the location of area associated with the Yellow Ditch and the mapped streamside tailings associated with Silver Bow Creek. Lands located between these features and adjacent to them are contaminated to varying degrees by tailings and air fall. Hazardous materials are released from the land surface and soils by infiltrating precipitation, as the water table contacts the hazardous materials and by the infiltration of ditch water and Silver Bow Creek water through contaminated soils. The streamside tailings have been characterized in Titan (1995). They have also generally assessed water quality impacts in the streamside tailings area. The regional groundwater study is beginning characterization of the Yellow Ditch deposits (Titan, 1995)(Woessner, 1995). Silver Bow Creek, the Yellow ditch during its operation, and related irrigation ditches are all losing water
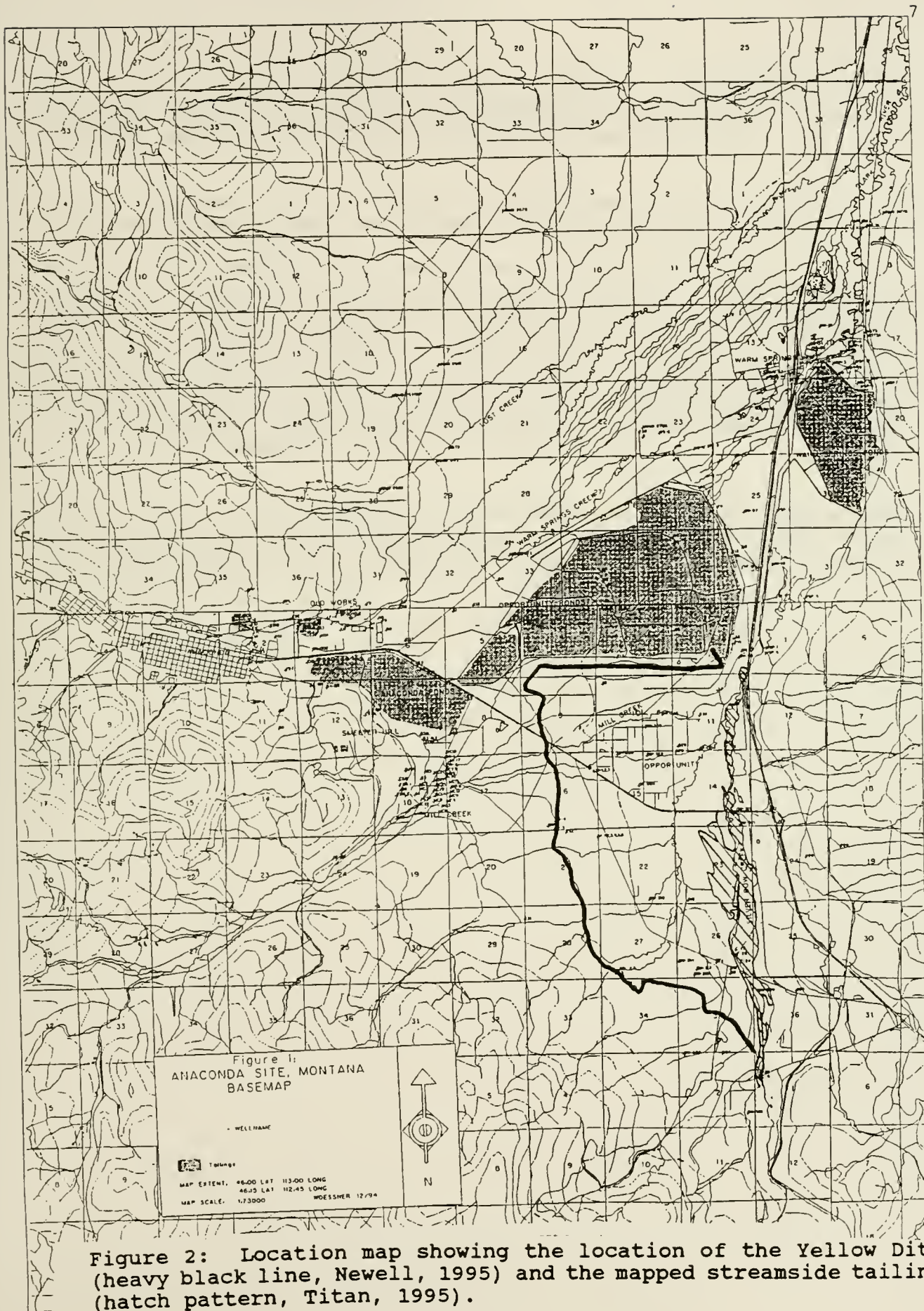
Figure 2: Location map showing the location of the Yellow Ditch (heavy black line, Newell, 1995) and the mapped streamside tailings (hatch pattern, Titan, 1995).

to the groundwater system (Titan, 1995). Concentrations of cadmium, iron, and manganese exceeding drinking water standards occur at depths of 10 to 15 ft below the water table.

Larson states on page 38 that groundwater flow rates from the Milltown reservoir are lower than calculated in my report.

The hydraulic conductivity value and flow rates calculated for the Milltown site were prepared using standard hydrogeological techniques. Hydrogeologist not use to working in highly conductive aquifers are often skeptical of high hydraulic conductivity values. Mr. Larson only questions the values used, he does not offer an alternative based on field derived values. Hydraulic conductivity values that characterize the similar coarse valley sediments found in the Missoula Valley near Milltown are often higher than the value used in Woessner's report (Miller, 1991).

Miller, R.D., 1991, A numerical flow model of the Missoula aquifer: Interpretation of aquifer properties and river interaction. Master of Science Depart. of Geology, University of Montana, Missoula, MT., unpublished, 301 pp.